Projects
The PhD project proposals listed below will be considered for 2020/21 studentships in the Department of Informatics to start in October 2020 (but an earlier start in April 2020 is possible). This list is not inclusive and the potential applicants can alternatively identify and contact the appropriate supervisors outlining their background and research interests or proposing their own project ideas. The PhD projects are listed in two groups. In the first group are the projects with allocated studentships, that is, each project in the group has one allocated studentship. The remaining studentships will be considered for the projects listed in the second group. The number of these studentships is smaller than the number of the projects in this group.

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Projects with allocated PhD studentships

**Algorithms and Data Analysis**
Supervisors: Dr Dimitrios Letsios

One PhD studentship will be allocated to one of the following three projects which lie at the intersection of algorithms, computational optimization, and data science.

1. Algorithms for Data-Driven Resource Allocation under Uncertainty

   Data analytics allow making future predictions so that organizations become proactive by anticipating outcomes based on data and not only assumptions. For example, predicted demand, travel times, and failures of vehicles enable making robust decisions, e.g. assignments of jobs to vehicles, for organizations in the transportation domain such as Royal Mail and London Ambulance Service. Efficient allocation of the organizations' limited resources is essential to guarantee their viability. The challenge is to effectively exploit the structure of predictive models' outcomes, typically in the form of uncertainty sets. The project aims to (i) design efficient solution methods for solving discrete optimization problems under uncertainty, (ii) develop formal proofs and analytically derive performance guarantees theoretically justifying proposed approaches and quantifying the predicted parameter uncertainty impact on the computed solutions, (iii) propose recovery algorithms in the presence of unexpected events, and (iv) validate the proposed approaches using real data.

2. Scheduling with Forecasts

   Scheduling algorithms may optimally assign resources, e.g. machines and energy, for executing tasks over time. Optimal schedules allow efficiently using servers in data centers, house appliances in smart grids, machines in product manufacturing, and result in substantial economic benefits. In this context, the exact amount of resources requested at each time is usually unknown beforehand. A remedy to this situation is using online algorithms that take decisions when requests become known. An alternative approach exploits forecasting techniques that predict future demand with historical data. However, these forecasts are subject to prediction errors. This project aims to (i) design algorithms for scheduling problems with demand forecasts and analyze their performance theoretically, (ii) investigate the trade-offs between taking decisions in advance or online, and (iii) evaluate the performance of the proposed approaches numerically.

3. Optimization with Trained Machine Learning Models

   Machine learning produces models from historical data, e.g. boosted trees and neural networks, which are able to make useful predictions. For instance, in engineering, we may predict the energy consumption of a chemical reaction subject to initial input conditions. But, after learning, we may want to exploit the resulting model for solving a larger decision-making problem, e.g. select the optimal initial conditions of a chemical reaction for optimizing the energy performance. In this setting, we may repurpose the usage of trained machine learning models by embedding them into larger optimization problems. These challenging problems have applications in different domains, e.g. healthcare and marketing, and exhibit novel difficulties. The project aims to (i) leverage the combinatorial structure of trained machine learning models, (ii) tailor powerful discrete optimization techniques for solving these problems efficiently, and (iii) substantiate the proposed methods with real data using commercial optimization software.
Efficient Mechanism Design for Markets and Reallocation of Goods
Supervisor: Dr Bart de Keijzer

This project focuses on the designing computationally and economically efficient mechanisms for market and exchange platforms.

On such platforms, a number of agents are present who have the intention of selling or buying items from other agents. A mechanism interacts with these agents and determines, based on this interaction, how the agents should trade and against which payments. The agents are assumed to act rationally, in the sense that they have a certain utility function which they want to optimise: For example, a natural setting would be one where agents want to maximise the total value of the items received, plus the payment that they potentially receive in compensation for losing some of their goods. The agents will interact with the mechanism in such a way that their utility is optimised, and mechanisms for such scenarios need to be designed in such a way that trade happens in an optimal way, while agents are not able to "cheat" the mechanism for their own benefit. Moreover, these mechanisms should perform their computations reasonably (and provably) fast. How to design the trading mechanism in such a way that these requirements are satisfied?

As there are many details that need to be specified in the above sketch to yield a very concrete model, this gives rise to a wide range of interesting mechanism design challenges. Different properties of the market require different mechanisms, where one can think of e.g. a static "one-shot" trading scenario versus a scenario where agents can dynamically enter and exit the market, or indivisible versus divisible goods, shareable vs unshareable goods, etc. In this project we will work on trying to solve various challenging variants of this design problem.

This is a project in algorithmic game theory, which means that it lies in the intersection of theoretical computer science and economics. This project relates strongly to computational complexity theory, approximation algorithms, matching theory, auction theory, and (clearly) mechanism design. This is a theoretical research field which is in the lucky position of also being relevant in practice: As examples of where this field is applied, one may think of ad-auctions in search engines, and various automated market platforms where goods are exchanged, or where clients are assigned to service providers (think of various popular platforms for taxi drivers, finding holiday accommodation, food delivery, and transportation services for goods).

Imperfect Rationality and Computation
Supervisor: Professor Carmine Ventre

Algorithmic Game Theory is a research field that provides a set of tools to account for strategic reasoning in computer science. One assumption underlying much of the work in the area is, however, pretty limiting: agents need to be fully rational. This is unrealistic in many real-life scenarios; we, in fact, have empirical evidence that people often misunderstand the incentives and try to game the system even when misbehaving is against their own interest.

This project will look at novel approaches to deal with imperfect rationality, including the analysis of known systems and the design of novel ones. This will involve theoretical work (such as, mechanism design) as well as more applied approaches (such as, agent-based modelling) to get a better understanding of the strategic interactions within a population of agents with imperfect rationality.
Understanding the Complexity of Negotiations  
Supervisors: Dr Alfie Abdul-Rahman & Dr Rita Borgo

A negotiated text is the product of a formal decision-making process where a text has been negotiated and drafted over a period of time. Many of the foundational texts of the modern world have not been written by individuals, but negotiated by groups of people in formal settings. For example, treaties between states such as the Universal Declaration of Human Rights or the Treaty of Versailles; or constitutions, such as the one negotiated by the American states in the Constitutional Convention of 1787.

During such negotiations, it is important for us to keep track of the delegations and their involvements in order to grasp their influence on the negotiation process either using techniques such as close reading, distance reading, or machine learning. Even relatively short historical documents written collectively in this way have been the product of thousands of specific proposals and decisions.

This project will apply a visual analytics approach towards the understanding of the complexity of a negotiation and the influence of the delegations during a negotiation process.

Possible research questions:

- Developing new static and interactive visualization to assist with data discovery and insight generation in large datasets of events within interacting timelines.
- Developing new approaches to show the evolution of complicated, technical documents over the period of months or years.
- Developing new approaches for indexing the datasets related to the negotiation of documents, and more intuitive displays of the results.
- Developing natural-language-based approaches to relate information captured in ‘informal’ archives (such as private diaries, letters, social media feeds etc.) to the formal records of a negotiation.

This project will work closely with the Quill Project, based at Oxford University: https://www.quillproject.net/

Visual recognition with minimal supervision in deep learning context  
Supervisors: Dr Miaojing Shi & Dr Michael Spratling

The goal of this PhD is to study object detection/segmentation in images or video with minimal supervision. This task will be placed into a setting where only image-level annotation is provided. To begin, additional supervision such as clicks, strokes, or bounding boxes may also be assumed. Towards the end of the PhD, the student is expected to work with datasets of mixed levels of supervision, including a harder, semi-supervised setting where there are only a few image-level labels as well as a large amount of unlabeled images.

Several ideas can be investigated in the context of deep learning. For instance, generative adversarial learning can be employed to either augment the dataset or bridge the predicted detections with their ground truth. Recurrent neural networks can be applied to video segmentation in particular to localize and segment semantic parts across nearby frames. On unstructured image datasets, ideas like deep metric learning and random-walk label propagation can be extended across pairs or groups of images. Cross-category transfer learning can be a further extension.

Few-shot learning is another challenging direction to explore. After learning on a set of base classes with abundant examples, new tasks are given with only few examples of novel (unseen) classes. For
such cases, the learning strategy of multi-million parameters architectures in deep learning needs to be rethought in order to allow the networks to squeeze out the maximum amount of information from the few available samples.

Projects for the remaining 2020/21 studentships

**ActOML: Active and Online Learning for Delaying Time Decay in ML Security Tasks**
Supervisor: Professor Lorenzo Cavallaro

Concept drift strongly affects malware classifiers [1]: when the statistical properties of testing malware objects change with respect to those the classifiers were trained against, the assumption that training and testing datasets are independent and identically distributed does not hold anymore. As such, the performance of malware classifiers decay over time.

We have recently explored space and time evaluation bias and the understanding of time performance decays of ML classifiers in security tasks under realistic settings due to concept drift [2]. This PhD proposal aims to build on such work and improve the robustness of malware detection algorithms against time decay (safe AI). To this end, we will develop novel active and online learning strategies for malware classifiers with the idea of exploring robustness against adversarial ML [3] as well. In this context, the proposal may venture on exploring traditional as well as deep machine learning to understand whether recent advances, such as Trusted Neural Network [4], represent the ideal framework to encode additional logical constraints to harden classifiers against such threats.

The proposals requires working at the intersection of program analysis and machine learning for systems security and the successful candidate is required to have a solid programming and CS/CEng background with a particular passion and knowledge in the foundations of systems, program analysis and machine learning. Given the nature of the research, the proposal links perfectly with the aims of the Security Hub at King's.


Administrative Access Control Policies
Supervisors: Professor Maribel Fernandez & Dr Jose Such

Administrative access control policies specify the rights that security administrators have in the system (e.g. to add or remove users, or change users’ rights). These policies are critical to ensure the overall security of the system, but not much work has been done on the development of general models for administrative access control. In this project we aim to define formal generic models of administrative access control, based on the Category-Based Meta Model of access control (CBAC), which can be used to analyse access control systems and help identify the impact of changes made by administrators (impact change) on the overall security of the system.

“Alexa, cover your ears!”: Privacy-Aware AI Personal Assistants
Supervisor: Dr Jose Such

AI personal assistants are becoming mainstream in practice, with the widespread introduction of desktop, phone and home assistants. For instance, over 70 million users utilise smartphone assistants like Siri, Google Assistant, and Cortana every day; and smarthome assistants have been sold in massive numbers, like the five million units of Amazon Echo with the Alexa personal assistant sold in less than two years. However, recent incidents involving AI personal assistants like Alexa recording a private conversation and sending it to a random contact, have increased users’ privacy concerns, with some users trashing their assistants all together and companies like Mattel cancelling assistant projects. It is therefore paramount to consider and respect users’ privacy to realise the benefits of AI personal assistants and foster trust from users. In this project, you will formalise the social norms that govern information sharing, management, collection, processing and learning in AI personal assistants. Based on this, you will design novel methods to personalise privacy in AI assistants based on the social norms but also on the users’ contextual, group, and individual preferences with an optimal accuracy-intervention trade-off.

Analysis of Contingent Liabilities in Debt Sustainability Analysis (DSA)
Supervisors: Dr Kevin Lano

Debt sustainability analysis is of critical importance to national economic management, particularly for developing economies. However, existing DSA models are often simplistic and fail to take into account contingent liabilities or the probabilistic nature of economic variables (Haughton, Commonwealth Secretariat, 2016). The research involves identifying and evaluating alternative approaches for DSA that provide stochastic modelling of debt and contingent liabilities, and comparing to standard models as used by the World Bank and IMF.

Analysis of Novel Interaction Methods in Programming Education
Supervisors: Professor Michael Rolling & Dr Neil Brown

The goals of the design of Frame-based editing [1] was to achieve improvements in various aspects of learning to program. Fewer syntax errors, better motivation, faster achievements, better retention, improved general satisfaction. Does this design achieve these goals? We don’t know.

This project would study the effectiveness of Stride compared to other systems with real users. We envisage that multiple user-studies with pupils in classrooms would be part of these investigations. Studies would employ methodologies from educational and computer science research.

[1] https://www.greenfoot.org/frames/
Automated Signature Generation for Network Intrusion Detection Systems (NIDS)
Supervisor: Dr Fabio Pierazzi

A Network Intrusion Detection System (NIDS) is a probe that passively monitors network traffic and triggers a “security alert” whenever a signature matching a particular pattern is found. However, signatures are still mostly generated manually, a process which is error-prone and time consuming.

This project will explore how AI and ML can support automated generations of signatures which are effective, efficient and interpretable. Evaluations will include adaptivity to different network environments, and performance speedup in terms of DR and FPR with respect to manually-defined signatures and existing statistical approaches.

Backbone Guided Local Search Methods for MAX-SAT
Supervisors: Dr Kathleen Steinhofel & Dr Dimitrios Letsios

Satisfiability (SAT) is a key problem in combinatorial optimisation and has a huge range of real-life applications. It seeks for a given Boolean Formula (conjunctive normal form) an assignment of variables such that the formula returns True. In case such an assignment does not exist, we seek an assignment that satisfies a maximum number of clauses (MAXSAT). As backbone structure, we denote the set of variables that have the same assignment in all optimal solutions.

Knowledge about the backbone structure can be used to guide heuristic methods which aim to find near optimal solutions. For instance, the size of the backbone can give indications of how many optimal solutions exists and consequently how hard it is for the search method to converge to an optimal solution. The guidance can be provided in two different types:

1. Deriving instance dependent methods by using pre-processing to approximate the backbone structure and to derive parameter settings for local search.
2. Estimating the backbone structure based on configurations visited by the local search method.

The findings will lead to faster convergence to optimum solutions and more importantly can produce methods which adapt to instance dependent properties. At the same time, methods to derive and analyse the backbone structure can be used to classify candidate solutions and to model additional, sought after properties such as robustness of candidate solutions.

Behavioral Modeling of Process Memory for Real-Time Detection of Attacks
Supervisor: Dr Fabio Pierazzi

Memory vulnerabilities such as buffer overflow, heap spraying, heap vulnerabilities, are still one of the major threats in all modern systems. Most modern approaches to detect memory attacks are based on heavyweight monitoring and analysis which causes significant overhead and prevents real-time application. This project will explore how AI and ML can be used to create a behavioral model of process memory for real-time anomaly detection of attacks occurring in memory.
Better Error Help Using Large Scale Programmer Data
Supervisors: Professor Michael Kolling & Dr Neil Brown

Could large scale beginning programmer data be used to give useful hints and help to beginners stuck on an error? For example, if a novice had problems with a task, could perhaps useful hints be automatically generated by analysing previous users who had similar problems, what they did, and whether their actions led to solving the problem?

Making use of the Blackbox data set [1] is one option to automatically generate helpful hints and tips for novice programmers.

[1] https://bluej.org/blackbox/

Big Data in Programming Education
Supervisors: Professor Michael Rolling & Dr Neil Brown

The Blackbox project has collected a large amount of data about the behaviour of novice programmers. We have data about hundreds of millions of programming sessions. So far, this data has been analysed only very superficially. An interesting project would be to use a big data approach for deeper analysis of this data set, and to work out what we could learn from this.

Characterization of Immunoglobulins
Supervisors: Professor Costas Iliopoulos, Dr Sophia Karagiannis & Dr Grigorios Loukides

Antibodies, or immunoglobulins, belong to the ‘gamma globulin’ protein group and can be found mainly in the blood of vertebrates [1]. Antibodies constitute the major serological line of defense of the vertebrates with jaws (gnathostomata) by which the immune system identifies and neutralizes threatening invaders, such as viruses, fungi, parasites, bacteria. The contrivance underlying the reaction efficiency of our immune system to specifically recognize and fight invading organisms or to trigger an autoimmune response and disease still remains to be elucidated. The efficient reaction of our immune system against all kinds of intruders is highly dependent on the number, condition and availability of antibodies, as reaction times are ‘key’ to the successful elimination of the foreign pathogen.

The importance of antibodies in health care and the biotechnology industry demands knowledge of their structures at high resolution. This information can be used for antibody engineering, modification of the antigens binding affinity and epitope identification of a given antibody. Computational approaches provide a cheaper and faster alternative to the commonly used, albeit laborious and time consuming, X-ray crystallography. Available immunogenetics data can be utilized for computational modelling of antibody variable domains. Standardized amino acid positions and properties can assist in optimizing the relative orientation of light and heavy chains as well as in designing homology models that predict successful docking of antibodies with their unique antigen. As a result, it comes down to identifying conserved motifs or patterns that are implicated and mediate antibody-antigen interactions.

Detection of such motifs by simple sequence comparison is impossible. Consequently, our research is fixated on the investigation of alternative approaches to efficiently study antibodies, mainly by the
multimodal fusion of information from genetic, structural and physicochemical analysis.

All in all, herein we propose a holistic approach in the realm of immunoinformatics that will focus on elucidating the mechanism of antibody-antigen recognition. The results and the final tool (in the form of either an online service or a downloadable tool) will be made freely available to the scientific community. We are confident that many fellow researchers from all walks of immunology, bioinformatics and antibody-related sciences will benefit from such a tool, both in terms of applied research and basic understanding of the function of CDRs.

Nowadays, it is certain that such specialized and specific recognition properties cannot be based on random and hypervariable sequences. It is just that using the 20 amino acid code is not a suitable approach to explain the phenomenon. Therefore, herein, we will calculate more than 430 different physicochemical properties to represent each residue of all antibodies, in an effort to identify what is the right dictionary (or indeed the right combination of dictionaries) required to decrypt the antibody-antigen interaction puzzle. The calculation of the physicochemical properties will be done using the QSAR module as it is implemented into the Molecular Operating Suite (CCG).

A brief overview of our main objectives includes the following:
• Collecting and building the working dataset
• Collect and curate antibody structural data from numerous databases
• Deep learning for feature extraction and prediction • Predict reliable classification markers through the use of convolutional neural networks (CNNs)

Computational Analysis of Ageing Brains
Supervisors: Dr Kathleen Steinhofel & Professor Zoran Cvetkovic

The ability to acquire and store information is a key function of the brain. This ability is affected by ageing and in various age-related disease, including dementia. In old age the acquisition of new information is more difficult than in young age. Moreover, updating of acquired information is also affected by ageing. The mechanistic basis of the age-related decline is not well understood. It is known that changes at synapses, the connections between nerve cells, are the basis of information storage. But it remains unknown how the synaptic basis of information storage changes with age.

Recently, ultrastructural changes at synapses were discovered and analysed after training in a memory task in young and aged mice. In the research programme, we want to investigate the impact of these changes by using computational approaches based on models of these biological observations. In addition to the modelling of ultrastructural changes, the regulatory function and expression level of microRNA in the neuro cell will be analysed towards the impact to the ability to store information. The findings will not only advance insights into mechanisms of information storage, but also support the analysis of age-related diseases, such as dementia, that affect cognition.

The supervisor team will include Prof Peter Giese (IoPPN) and Anna Zampetaki (Cardiovascular Division).
Contextualising Big Programming Data  
Supervisors: Professor Michael Kolling & Dr Neil Brown

The Blackbox project has been running for over five years. It collects data from novice programmers: source code that is written, compilation errors displayed, and various other data about a programmer’s interaction with the BlueJ IDE. The data is collected without any further context: we do not know the age or experience of the programmer, whether they are on a course or not, whether they are doing well on their assignments, and so on. This allows for a large data set, but one that is stripped of useful context. This project would investigate collecting useful data (e.g. experience, course grades) for a subset of Blackbox participants, to provide a richer subset for other researchers, and to be used in the project to investigate associations between programming activity and success on a course.

Data Science Strategies for Cancer Immunotherapy Application  
Supervisors: Dr Sophia Tsoka & Dr Grigorios Loukides

Computational analysis of biomedical datasets can lead to understanding of disease systems and therapeutic interventions. We propose a project that will target the computational analysis of experimental data on immune activation against cancer using antibodies. Integration of experiments with publicly available data on known cellular interactions will establish a resource for data mining. Such a resource will be used to implement machine learning algorithms to link gene features to cancer response, network analyses to represent molecular interactions and logical modelling to explore regulatory effects from proteomic experiments. The combination of these Data Science frameworks will elucidate signalling networks related to the control of tumor growth by antibody-enhanced human immune cells and identify key altered pathways and their regulation state. The long-term prospect is to improve understanding of disease mechanisms and cell signalling, so as to improve the design of novel drugs and therapies.

Development of Scalable General Artificial Intelligence (AI) Problem Solving Systems  
Supervisor: Dr Amanda Coles

This project aims to develop scalable general Artificial Intelligence (AI) problem solving systems, capable of reasoning with the large combinatorial problems that arise in effectively managing the oversubscribed infrastructure of densely populated cities. This project builds on a study, supervised by Dr Amanda Coles (KCL Informatics) an expert in AI Planning and Professor Christopher Beck (University of Toronto) an expert in Constraint Programming (CP), exploring the application of CP and AI planning to disruption recovery in the UK rail network. The PhD project aims to significantly increase the solution quality and scalability of AI problem solving technologies, based on our new understanding of the strengths these approaches, by automatically decomposing problems so CP solvers and AI Planners solve the parts best suited to their strengths. The successful candidate will extend the state-of-the-art in AI research and have the opportunity to apply this to real-world UK rail network problems.
Distributed Computing by Population Protocols
Supervisor: Professor Tomasz Radzik

Population protocols are a simple model of distributed computing, with applications extending to other areas, including processes in chemical network and online social networks. This model assumes that the computing system consists of a large number of identical devices, called agents or nodes, which communicate with each other in pairwise interactions. The pattern of interactions depends on external factors and interacting nodes follow a simple protocol, which should ensure that all nodes gradually learn some global property of the system. This project is a study of the computational potential and limitations of this model and an investigation of applications.

Formal verification of smart contracts
Supervisor: Dr. Hana Chockler

Formal verification of software is gaining popularity for verifying increasingly complex and safety-critical software. While the full verification task is unsolvable (the problem is easily reduced to the halting problem, which is undecidable), numerous existing solutions to subproblems are general enough to provide thorough verification and correctness assurance for real-life systems. There is a number of teams currently working on tools for software verification, with the Formal Verification Team at the University of Lugano (USI), led by Prof. Sharygina, being one of the most established ones. Prof. Sharygina recently received Swiss government funding for a large project titled “Beyond Symbolic Model Checking through Deep Modelling”, in which Dr. Chockler (the first supervisor) is a named collaborator. The proposed Ph.D. project will be done in collaboration with the team at USI. The student will be able to travel to work face-to-face with the team in Lugano, and close collaboration via skype and emails is expected when the student is in London.

Current model-checkers (automated formal verification tools) are mostly suitable to verify programs in C and C++. In this project, we will research the direction of formally verifying smart contracts. The student will research different options of extending the verification platform to smart contracts written in Solidity (or other languages) and will analyse whether the verification should be done on the source code level or on the bytecode level.

Smart contracts are typically small. However, they interact with other contracts and are being called in a loop or recursively, thus leading to a number of subtle bugs (see, for example, the exploit of the DAO bug, leading to loss of $50 Millions). It is then reasonable to expect that the best way to formally verify smart contracts is by using modular reasoning: for each smart contract, the other contracts with which it interacts can be considered an environment. This environment can be overapproximated using learning techniques in combination with sampling and traditional model checking approaches. After verification of a single contract passes successfully, some symbolic representations of the contracts with respect to the correctness properties will be combined to prove correctness of the overall system.

The project will include a significant implementation component. The implementation is done using the software verification platform developed at USI. The main development task is the new front-end, so that the verification platform is able to analyse programs in Solidity (or EVM bytecode). As model-checkers require writing a large and complex software, the advantage of having such a software available already and being in contact with the team that develops and maintains it is hard to overestimate. In addition, being a part of a very active
and experienced research team guarantees discussions and collaborations that further aid the research, especially in the initial stages.

**Learning of Software Design Patterns**  
**Supervisor: Dr Hana Chockler**

A software engineer joining a development team typically does not start writing software immediately; first, she needs to understand the large existing body of code and recognise the key components and how they interact with each other. Documentation is typically sparse and not updated regularly. The software, on the other hand, is large and difficult to understand. “Software is like entropy: It is difficult to grasp, weighs nothing, and always increases.” (Norman Augustine).  
Project development tools aid understanding the software by identifying the participating classes, and the static dependencies between them.

The next step is to identify a set of design patterns common to this project, e.g.: when are resources allocated and freed, in what manner are certain components of a class visited? In this area, the static analysis tools are insufficient. The proposed project is to learn the design patterns in the given code automatically by applying grammatical inference (learning) algorithms.

The benefits for automatically learning design patterns go beyond helping the software engineer getting a clear representation of the design patterns. An automatic analysis can discover areas where the same goal is achieved by utilising different patterns: one of the patterns can be erroneous or obsolete, or the multitude of patterns can point to the lack of precise development guidelines for a certain task, indicating a need for a guiding design pattern. These challenges require developing learning algorithms that can learn several automata simultaneously, such that the resulting automata correctly capture the main abstractions in the given corpus of code.

The project will build upon previous research results of Dr Hana Chockler in collaboration with the University of Oxford.

**Machine Learning Augmented Algorithms**  
**Supervisor: Dr Frederik Mallmann-Trenn**

Machine learning and in particular deep learning has gained much attention over the past several years, yet theoretical understanding is still very limited. As a remedy, a recent line of research emerged in which neural networks are used as a black box in many online problems, where the data arrives over time. The idea is to use a neural network to give predictions of the data that will arrive in the stream. The goal is to design algorithms that perform much better than previously if the prediction is good and on the other side, to show that even if the prediction is bad, the solution found by the algorithms is still reasonably good.

A toy example is the ski rental problem, where each day a skier on vacation has to make a decision: either rent skis for 10$ or buy skis for 100$. We assume that the ski trip can end abruptly (chosen adversarially). See [https://en.wikipedia.org/wiki/Ski_rental_problem](https://en.wikipedia.org/wiki/Ski_rental_problem) for classical algorithms. Now if we assume that a neural network makes a prediction on when the ski trip will end, how much better can we do? The field is very young and great problems of practical and theoretical importance await!

Model Driven Engineering in Finance  
Supervisors: Dr Kevin Lano

In the finance industry there is a strong emphasis on the rapid time-to-market of new financial software products and financial models, which can conflict with the achievement of software quality and correctness. The proposed research will investigate how these conflicting aspects can be managed and partly resolved through, for example, the reuse of trusted components, and the use of model-based rapid application development and iterative (agile) development.

Modular and Hierarchical Learning and Representation of Large Software  
Supervisor: Dr Hana Chockler

A software engineer joining a development team typically does not start writing software immediately; first, she needs to understand the large existing body of code and recognise the key components and how they interact with each other. Documentation is typically sparse and not updated regularly. The software, on the other hand, is large and difficult to understand. “Software is like entropy: It is difficult to grasp, weighs nothing, and always increases.” (Norman Augustine).

Being able to represent large software in a graphical way with the ability to zoom in and out of components would help tremendously towards understanding of the software structure and its functionality. The proposed project is to learn a hierarchical compositional structure that will be used for such a graphical representation. The most likely candidate for such a hierarchical structure is state charts which have been used for software design for many years.

There are no existing learning algorithms for learning state charts. There is, however, a number of algorithms for learning similar structures, such as finite automata, transducers, etc. The first part of the proposed project consists of constructing a new learning algorithm for learning state charts. The second part of the proposed project is using this algorithm to learn complex software in a hierarchical way, allowing the user to zoom in and out of components (composite states).

The project will build upon previous research results of Dr Hana Chockler in collaboration with the University of Oxford.

Monitoring Compliance with Dynamic Security Policies under Uncertainty  
Supervisors: Dr Natalia Criado & Dr Jose Such

This project will develop the first monitor capable of checking compliance with dynamic and adaptable security policies on the basis of incomplete and uncertain observations. Most existing proposals on security policy compliance monitoring assume that monitors have perfect information and observation capabilities, or that security policies are fixed and known at design time. However, this assumption is too strong for modern hyper-connected, socio-technical, and cyber-physical systems due to their inherent uncertainty, incompleteness and dynamism.

For example, in a business environment it is: unfeasible to observe all files uploaded/downloaded...
to/from public cloud services, since employees can perform these actions using non-corporate network/devices; impossible to detect all sensitive information contained in files with complete certainty; and security policies controlling access to public cloud services can change as a result of new legislation (GDPR) or threats. This project, will propose a novel security policy monitor for hyper-connected, socio-technical, and cyber-physical systems.

Multiple Robots Performing Random Walks
Supervisor: Dr Frederik Mallmann-Trenn

The goal of the project is to study distributed algorithms for dynamic and noisy settings robot swarms, and biological systems. We will seek new algorithms to solve fundamental problems of communication, construction, reaching agreement, estimation, data processing, searching, shape formation, task allocation, and more.

One example is the setting of [1], where robots have to estimate the fraction of black tiles in a grid. Each of the robots is very simple and performs a random walk. Whenever, two or more robots are close to each other, they can communicate with each other. In the end, the robots have to agree on a joint estimate of the fraction of black tiles. The arising questions here are:

- How much can multiple random walks speed up the process?
- How many samples have to be taken?
- What happens if the communication is noisy?

The goal is also to collaborate with researchers in the robotics community by modelling and analyzing systems theoretically. In addition to a solid understanding of Markov chains, students should be interested in collaborating with researchers across different disciplines.

[1] https://dl.acm.org/citation.cfm?id=3237953

Network Optimisation Algorithms
Supervisors: Professor Tomasz Radzik & Dr Kathleen Steinhofel

Network Optimisation problems are computational problems with input data referring to a network structure. Such problems occur in computer science, operations research, engineering, and applied mathematics. From the computer science point of view, the general objective of studying network optimisation problems is to develop efficient algorithms, which provide strict performance guarantees. This project will focus on algorithms for network optimisation problems with the dynamic network structure, which changes over time. One of the applications is to provide efficient routing in networks where individual node-to-node links are not always available.

The Nexus between Crime, Mental Wellbeing and the Built Environment in Urban Areas
Supervisors: Dr Nishanth Sastry, Dr Rita Borgo & Dr Andrea Mechelli

This project will explore the nexus between crime, mental wellbeing and the built environment in urban areas, using London as a case study. Using a data-driven approach, the student will develop a holistic understanding of the spatial and temporal dynamics of crime. For instance, objective notions of crime such as real-time crime reports from Metropolitan Police can be compared with more
subjective notions of how safe a place ‘feels’, measured using crowdsourcing using the UrbanMind App. Spatial variation in crime levels and Temporal Dynamics (night vs. day or weekday vs. weekend) will be mapped. Machine learning on images from Google Street View, Flickr etc can shed light on how the built environment affects perceived notions of safety and whether it has an effect on actual crime, as hypothesised by the "Broken Window” theory. The results will be used to inform future work on urban wellbeing, as well as urban planning.

A Novel Model-driven AI Paradigm for Intrusion Detection
Supervisor: Dr Fabio Pierazzi

Intrusion Detection Systems (IDSs) are commonly deployed in networks and hosts to identify malicious activities representing misuse of computer systems. The numbers and types of attacks have been constantly increasing, and detection based on manually-defined signature is no longer a viable option. Hence, AI-powered IDS solutions have been explored to keep up the arms race and scale to new threats, but they are not yet deployed at scale in companies; this is mostly because such AI-powered systems cannot be trusted and are not interpretable [1], and they suffer from a lot of false positives preventing their applicability in real-world scenarios. In particular, a major limitation is that most existing solutions for AI-powered IDSs are data-driven, where the relationships learned from the data are often artifacts or domain-agnostic, and thus harder to trust and interpret even for network administrators.

This project aims to explore the design of a novel model-driven AI paradigm for intrusion detection, where expert knowledge is embedded in a model to characterize user behaviors (e.g., through formal logic [2]), with the purpose of identifying malicious activities with trust, interpretability and verifiability of the IDS decisions, in particular when deployed to real-world contexts. In other words, this project aims to advance the state-of-the-art in AI-powered IDSs by integrating expert knowledge in the models to achieve trust, interpretability and verifiability of decisions. This will increase the overall safety of protected users by making IDS systems more effective and reliable, and progress towards industry-wide deployment of AI-based solutions for intrusion detection.


Participatory Agent-Based Modelling of Emergency Department Patient Flow
Supervisors: Dr Steffen Zschaler & Dr Simon Miles

Emergency health care is in crisis; the core ’4-hour’ KPI has not been met since 2015. Emergency Departments (EDs) are socio-technical systems with complex interactions between a wide range of actors and with their urban environment. To help predict how changes in practice will affect the 4-hour KPI while ensuring patient safety and quality of care, we have been developing agent-based models (ABMs) of EDs, which can provide explainable analyses of behaviour of complex systems emerging from the lower-level interaction of large numbers of agents. However, ABMs currently are implemented in Java or C++, making them too technical to be understood and manipulated by clinical decision makers. Hence, findings from ABM-based analyses are often not translated into interventions. In this PhD project, you will explore how using domain-specific languages (DSLs) closely aligned with clinical staffs’ conceptualisation of the ED environment will affect acceptance of
ABM. We collaborate with King’s College Hospital ED and Westminster City Council.

**Personalised Medicine**  
Supervisors: Professor Costas Iliopoulos & Dr Sophia Tsoka

The explosion of human genomic data is a key driver of the current transition in healthcare to an era of personalised medicine. The correct assembly and subsequent analysis of this data is, therefore, crucial.

Algorithms can be designed to provide answers for the various and vast number of specific questions that collectively elucidate the (dis)functioning of a biological entity, at the most fundamental level. These algorithms can be categorised based on their purposes. For example, pattern matching/discovery algorithms can find biologically significant motifs in sequences; alignment algorithms can identify the similarity between sequences; and compression algorithms can allow the latter two problems to be solved in a more time- and space-efficient manner.

**Predictive Visual Analytics for Urban Contingency Planning**  
Supervisors: Dr Rita Borgo & Dr Grigorios Loukides

The aim of this project is to investigate the power of integrating predictive analytics and data visualization to address the challenge of generation, validation and deployment of contingency plans in the context of urban related scenarios.

Based on initial work already conducted in this area by both supervisors, the project will investigate development and evaluation of:

- algorithms for mining city rich data, both static (stored by the London Councils) and realtime (retrieved from mobile platforms, remote sensors, and social media), in order to predict emergencies efficiently and accurately;
- novel visual encodings to enhance the diagnostic and predictive capabilities of mining algorithms, through their integration within a flexible visual analytics system capable of supporting and leveraging domain expert knowledge.

Application domain: contingency plans are employed across different organizations, from government to businesses, to minimise risk of catastrophic impacts of unexpected events. Research will have impact beyond the city remit.

**PRISM: Adversarial Program Generation**  
Supervisor: Professor Lorenzo Cavallaro

Machine learning algorithms have a major weakness: they are susceptible to adversarial attacks [1], where the classifier is induced into making wrong decisions by an attacker that alters data at training-time (poisoning) or at test-time (evasion). In malware detection, this implies that an adversarial malware object is recognized (wrongly) as goodware by the classifier, and bypasses antimalware solutions. Most research efforts on adversarial ML have focused on the image, speech, and audio domains, where it is trivial to change raw data (e.g. pixels); the malware domain is much more challenging because it needs to change programs code while preserving their functionality. Hence, there is no clear understanding of adversarial attacks in the malware domain.

This proposal aims to study which adversarial attacks for malware are realistic, i.e., to determine
which adversarially-generated feature vectors can be transformed into real and functioning malware applications. Understanding what malware adversarial ML attack is realistic becomes fundamental to design appropriate defenses in this domain, and building more robust classifiers.

The proposal requires working at the intersection of program analysis and machine learning for systems security and the successful candidate is required to have a solid programming and CS/CEng background with a particular passion and knowledge in the foundations of systems, program analysis and machine learning. Given the nature of the research, the proposal links perfectly with the aims of the Security Hub at King's.


**Privacy in the Internet of Things**  
Supervisor: Professor Maribel Fernandez

Data Collection policies are used to restrict the kind of data transmitted by devices in the Internet of Things (e.g., health trackers, smart electricity meters, etc.) according to the privacy preferences of the user. The goal of this project is to develop cloud/IoT architectures with integrated data collection and data sharing models, to allow users to specify their own policies and trade data for services. For this, new data collection and data sharing models will have to be developed, with appropriate user interfaces, policy languages, and policy enforcement mechanisms. An important aspect of the project is the development of policy recommendation systems that can suggest/create policies based on user profiles, making privacy an integral part of the system (according to the “privacy-by-design” IoT paradigm).

**Programming as an HCI Challenge - IDE Interaction Design**  
Supervisors: Professor Michael Rolling & Dr Neil Brown

Frame-based editing with Stride [1] was a first attempt to revisit the design of program editing from an HCI perspective, in the context of novice programmers. What would it look like to approach professional IDEs from this perspective? This project would take a Stride-like approach to professional tools and design, build and evaluate a new, better editor.

[1] https://www.greenfoot.org/frames/

**Program editor design for accessibility**  
Supervisors: Professor Michael Kolling & Dr Neil Brown

Most program editors use text for editing. Screen readers can be used with text-based editing by
visually-impaired programmers, but the syntax can often be confusing. Whitespace and punctuation are highly significant in program text but often omitted or have poor interaction with screen readers. Block-based editors rely less on syntax, so are potentially more suitable for accessible programming - but blocks are often manipulated only through drag-and-drop interactions which are ill-suited to visually-impaired users. Our existing Stride editor combines keyboard interactions with structural programming, but does not yet have support for accessibility tools. This project would look at improving the Stride editor to work well with accessibility, especially for vision-impaired users, including the design, implementation and evaluation of the editor with actual users.

**Programming history for learning and reflection**
Supervisors: Professor Michael Kolling & Dr Neil Brown

Version control provides a way to store and view the history of program code. This is generally considered an advanced tool, used for collaborating or once a programmer is working on a large code base. This project would investigate the implications of using built-in automatic version control. Can this help during novice program development, can it help students in reflecting on their learning progress, and could it be used to provide more accurate programming assessment. This would involve the design, development and multiple evaluations of automatic version-control in a beginner’s IDE.

**Security and Safety of Cyber-Physical Systems**
Supervisor: Professor Luca Vigano

Cyber-Physical Systems (CPSs) are integrations of networking and distributed computing systems with physical processes and associated instrumentation that monitor and control entities in the physical environment, with feedback loops where physical processes affect computations and vice versa. Emerging applications of CPS include all the essential pieces of our social infrastructure: telecoms, banking, manufacturing, health energy, transportation, government smart cities. CPSs have effectively become one of the driving factors of the so-called fourth industrial revolution (Industry 4.0), but all the new opportunities opened by CPSs will only materialize if we can ensure their security and safety.

However, this need is often not addressed in current practice because of the major challenges that are posed by the heterogeneous and distributed nature of the systems and their interaction with the physical world and with the human users. As a consequence, there has been a dramatic increase in the number of attacks, e.g., influencing physical processes to bring the system into an undesired state. System failure can be extremely costly and threaten not only the system’s environment but also human life.

The main aim of this PhD project will be to develop model-based AI techniques for representing, analysing and reasoning about the security and safety of both the technical components of a CPS (control, computation, communication) and its social components (e.g., user interaction processes and user behavior) together and at the same time. The goal will be to overcome the limits of the state-of-the-art to devise methodologies and technologies for the formal validation of properties of CPSs to include the human element together with the technical in a holistic, socio-technical approach for security and safety, and to rebound the findings over the users through behavior change techniques. This will greatly simplify the design, development, deployment, and management of socio-technically secure CPSs, and thus have a disruptive and lasting impact.
Software Verification and Nominal Dependent Type Theory  
Supervisor: Professor Maribel Fernandez

Dependent Type Theory is a mathematical tool to write formal specifications and prove the correctness of software implementations. The proof assistants used to certify the correctness of programs (such as Coq), are based on dependently-typed higher-order abstract syntax. The goal of this project is to explore alternative foundations for proof assistants using nominal techniques. The nominal approach has roots in set theory and has been successfully used to specify programming languages. This project will focus on the combination of dependent types and nominal syntax, and explore the connections between the nominal approach and the higher-order syntax approach used in current proof assistants.

String Sanitisation with Applications to Internet of Things Data  
Supervisors: Dr Grigorios Loukides, Professor Costas Iliopoulos, Professor Luca Vigano

The overall aim of the project is to develop and evaluate a robust and efficient approach that allows organisations and businesses to protect the privacy of data represented as strings. The project will consider the protection of aggregated data (event sequences), as well as string databases, and it will also address the interrelated issues of usefulness, security, and scalability. It aims to develop a methodology (model, algorithms, protocols) for sanitising (i.e., transforming) data that is: (I) privacy-preserving, by designing and applying a privacy model along with algorithms for sanitising string data. (II) Utility-preserving, by designing measures and tools for quantifying the level of usefulness of data that must be traded-off for achieving privacy. (III) Secure and scalable, by designing efficient protocols that allow multiple parties to securely and jointly protect their data. The methodology will be evaluated on data from the Internet of Things (IoT) domain.

Temporal and Resource Controllability of Workflows of Autonomous Systems  
Supervisor: Professor Luca Vigano

Workflow technology has long been employed for the modeling, validation and execution of business processes, and will play a crucial role in the design, development and maintenance of future autonomous systems. A workflow is a formal description of a business process in which single atomic work units (tasks), organized in a partial order, are assigned to processing entities (agents) in order to achieve some business goal(s). Workflows can also employ workflow paths in order (not) to execute a subset of tasks. A workflow management system coordinates the execution of tasks that are part of workflow instances such that all relevant constraints are eventually satisfied.

Temporal workflows specify business processes subject to temporal constraints such as controllable or uncontrollable durations, delays and deadlines. The choice of a workflow path may be controllable or not, considered either in isolation or in combination with uncontrollable durations. Access controlled workflows specify workflows in which users are authorized for task executions and authorization constraints say which users remain authorized to execute which tasks depending on who did what. Access controlled workflows may consider workflow paths too other than the uncertain availability of resources. When either a task duration or the choice of the workflow path to take or the availability of a user is out of control, we need to verify that the workflow can be executed by verifying all constraints for any possible combination of behaviors arising from the uncontrollable parts. Indeed, users might be absent before starting the execution (static resiliency), they can also become so during
execution (decremental resiliency) or they can come and go throughout the execution (dynamic resiliency).

Temporal access controlled workflows merge the two previous formalisms by considering several kinds of uncontrollable parts simultaneously. Authorization constraints may be extended to support conditional and temporal features. This PhD project will aim to ensure the safety and trust of autonomous systems by reasoning about the temporal and resource controllability under uncertainty of the workflows that govern them.

**Towards Protection of Users in Online Social Networks**  
**Supervisor: Dr Guillermo Suarez de Tangil**

Methods currently used to detect unwanted content in Online Social Networks (OSN) suffer from a number of limitations. First, they are prone to produce unfair decision dominated by the skewed population they are modelled with. Second, algorithms are unable to explain why certain content has been flagged as unwanted.

Active adversaries are currently exploiting this flaws to evade the detection mechanisms placed in current OSN. This applies to several application domains such as: i) the use of spear phishing or malware attacks to enable cyber-dependent crime, ii) the use of coordinated harassment campaign to deliver harmful or deceiving content (e.g., politically-biased memes), or iii) the use of commercially-driven sensational content to deliver fake news.

The purpose of this PhD is to devise new disciplines aiming at protecting users, and specially minors, from malicious actions in OSN and understanding novel threats. The scope of the project will focus on studying the problem of online aggression from a broad perspective.

**Tracing Trust - Visual Frameworks for Explainable AI**  
**Supervisors: Dr Rita Borgo, Dr Daniele Magazzeni, Dr Alfie Abdul-Rahman**

Explainable Artificial Intelligence (XAI) is a topic receiving close review and increasing interest across different fields. Crucial to explainability is understanding of cause-effect relationships which in complex intelligent systems are anything but clear. Lack of ability to present the rationale behind a decision making process inevitably mines trust and introduces uncertainty with respect to accountability of consequences.

The proposed research program will focus on the creation of a theoretical and applied framework to support the creation of systems to help people interpret the reasoning behind decisions made by AI systems. The project will entail design, implementation, and testing of visualization interfaces connecting to and integrating with explainable intelligent systems designed by partners.

This project places itself across three different fields: visual analytics, human-computer interaction, and artificial intelligence.

Hub relevance: Autonomous Systems
The Underground Economy: Understanding and Modelling Misuse in the Darkest Corners of the Web  
Supervisor: Dr Guillermo Suarez de Tangil

Underground markets play a key role in the proliferation of cybercrime. Users with few technical skills can easily acquire services and tools in the darknet to set up their own criminal operations. An example is illicit crypto-mining campaigns, that use botnets rented in such markets to leverage stolen resources and covertly mine 4.4% of the entire Monero in circulation (circa 58 million USD) [1]. Profits generated by these campaigns introduce massive incomes to cyber-criminals. These incomes fuel the underground economy and gear other cyber-criminal activities. More importantly, these threats generally cause important economical loses to victims.

The purpose of this PhD is to develop data driven approaches to better understand how these communities are structured and the type of crimes they support.


Understanding Cyber-Dependent Crimes that are enabled by Malware from a Software Development Perspective  
Supervisors: Dr Guillermo Suarez de Tangil & Professor Luca Vigano

The goal of this thesis is to better understand cyber-dependent crimes that are enabled by malware from a software development perspective. The purpose is threefold: a) to profile malware developers, b) to understand their business model, and c) to measure the impact of malware trading in underground markets and surface forums. Throughout this Thesis, the PhD candidate will learn how to reverse engineer malicious code and feed this information to different machine learning algorithms. The candidate will also be conducting malware-related measurements in underground markets and darknet forums. The qualifications obtained by the candidate will be relevant to different stakeholders such as: i) low-enforcement and anti-crime agencies when designing strategies to prosecute these actors, ii) incident response teams and forensic analysts to make informed decisions when a malware is discovered, and iii) national advisory centres to understand novel infection vectors or CERTs to design both mitigation and early detection strategies.

Unstructured Big Data  
Supervisors: Professor Costas Iliopoulos & Dr Grigorios Loukides

A major challenge in today’s society is the explosive growth of unstructured data such as text, images, videos and speech data. These forms of data exhibit the three characteristics of velocity, volume and variety that make processing and comprehending them a challenging task.

The initial processing of this data is invariably done using automated methods, as manual processing would be prohibitively expensive. The output of this automated processing is uncertain, either due to inaccuracies or inconsistencies in the raw data, or due to the automated processing. The database community has recognised this phenomenon in recent years, and several probabilistic formulations of uncertain data have been proposed, with a focus on processing SQL-like or ranking queries on such data. However, the science of mining, pattern analysis and pattern discovery on uncertain data
expressed in probabilistic terms is very much in its infancy.

Mining probabilistic uncertain data to obtain reliable and actionable information is a critical challenge. Since the proliferation of "data science pipelines" uncertainties in one stage can propagate and magnify in later stages. It is essential both that uncertainty is processed appropriately by the system and that the data is not artificially made certain by, for example, choosing the most probable outcome at each stage.

The central hypothesis of this proposal is that the new field of algorithms on uncertain sequences that we propose is an important and broad foundation for representing and mining uncertain data arising in a wide variety of contexts. In addition, novel algorithmic techniques and ideas will be needed and could be useful for other high throughput data processing. The breadth of the proposed area investigation can be illustrated by the three abstract models given below:

A) Probabilistic sequences: they model a number of real-world data, as - DNA sequences, either to represent single nucleotide polymorphisms, or errors introduced by wet-lab sequencing platforms during the process of DNA sequencing.

- Converting sensor readings into meaningful human actions (e.g., accelerometer readings into kinds of human activity, using blood pressure/voice pitch to infer emotions) due to the process' intrinsically uncertainty.

- Software behaviour is often characterised in terms of sequences of events, such as the order of user interactions with a GUI or a web-page, the order of function invocations within a program, or the order in which network packets are sent to a server. A common assumption is that system behaviour is deterministic. It is however easy to envisage situations in which this assumption is violated. Network packets might arrive in a different order, depending on their route through a network, a unit of code might include stochastic behaviour to arise from random number generators, or different interleaving of concurrent behaviour.

B) Uncertain Event Sequences: arise from a number of sources including measurement error, randomness in the underlying phenomenon, and due to distributed and asynchronous data gathering. They are used in a number of real-world scenarios to model and analyse spatial or temporal data, which is of interest in diverse disciplines as computational neuroscience, earth science and telecommunications. Marked event sequences are even more general and can be applied to computer and economic systems for examples.

Uncertain Time Series: are most naturally associated with measurement errors, but can directly represent a range of variation (e.g. high/low stock prices in a day's trading, confidence intervals for predictions) or deliberate obfuscation for reasons of privacy preservation. They can be seen as special cases of event sequences, but while in uncertain time series the uncertainty lies in the value, in uncertain event sequences, the uncertainty is in the time that the event occurred.

Research Programme and Methodology:

We will focus on highly-scalable methods discovering repetitive structures in uncertain sequences. Given the uncertainty in the underlying data, these repetitions will of necessity be approximate, rather than exact.

There are two major technical obstacles to overcome: firstly, classical measures of approximation (edit or Hamming distance) are inadequate to measure similarity between uncertain sequences. One
objective of this project is to define new, alternative, well-founded and powerful approaches for measuring similarity between sequences. Secondly, we need to develop novel algorithmic techniques for solving problems in the context of uncertain sequences.

These problems are directly motivated by bioinformatics applications, such as studying genetic mutations; DNA sequence analysis of antibodies and identification of "hairpins" that occur in DNA sequences in Tuberculosis and HIV virus strains, respectively. However, they are also closely related to pattern discovery tasks that arise in other problem domains. Furthermore, they are also the most intensively studied problems in mining time series data and, to the best of our knowledge, these problems have not been considered in the uncertain time series framework, and it is not at all clear how to extend the known methods to this case. A solution is to build upon the experience we have in musical and biological computation pattern analysis, which share some characteristics with uncertain sequence processing, to suggest lines of attack.

Objectives:

1. Devise appropriate uncertain / probabilistic sequence formulations for modelling large-scale complex heterogeneous data.
2. Develop highly-scalable algorithms for pattern / motif discovery and sequential pattern mining in uncertain sequence data.
3. Build a theoretical framework for pattern discovery in dynamic, streaming and high-throughput uncertain sequence data.
4. Develop robust and well-founded methods for inferring actionable models of uncertain sequence data.
5. Devise appropriate and tractable formal frameworks for modelling stochastic dependencies in uncertain sequence data.