Network Models, Multimodal Deep Learning, and Complex Systems

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My previous research directions are on parallel and distributed solutions for bioinformatics problems and machine learning. My future research plans span the following topics:

- Big data visualisations through graph and network models. These models enable summarisation, pattern recognition, similarity scoring and trend analysis among others.
- Applications of complex systems and game theory to study multiagent' interactions of various applications.
- Explainable Artificial Intelligence by building deep learning models for various applications to enhance the performance of the state-of-the-art solutions.
- Network dynamics and analysis for various applications.
- Tensor multiway analysis applications in machine learning and deep learning such as in multimodal fusion.

Application and contact

We are looking for candidates with a background in Computer Science, ideally with good competency in programming and software engineering practices. Those with Artificial Intelligence background are also encouraged to apply if they have good programming skills. Professionals with no previous degree, but excellent industry experience, are also encouraged to get in touch. Queries are encouraged and welcome to Dr Manal Helal (m.helal@herts.ac.uk).

Ph.D. Project Ideas

1. Engineering Patents visual summarisation Capture for comparisons and similarity scoring

Key words: Patents Mining; Data & Text Mining; Semantic Analysis; Functional Analysis Diagrams; Graph Data Modelling; Data Visualization; Similarity Scoring; Big Data Analytics; Machine Learning; Artificial Intelligence; Deep Learning; Natural Language Processing; Ontology Building; Network Analysis

Engineering patents provide a rich source of information about design innovations. Patent mining techniques employ various technologies, such as: text mining, machine learning, natural language processing, ontology, among others. A graph data modelling approach is developed for building a semantic database of patents from functional representations of mechanical designs. The method has several benefits: The schema-free characteristic of the proposed graph modelling enables the ontology it is based on to evolve and generalize to upper ontologies across domains, and to specify to lower ontologies to more specific domains. Graph modelling benefits from enhanced performance of deep queries across many levels of relationships and interactions, data visualisation, application of network alignment methods to score similarities and recurring patterns, network analysis methods to identify trends, hubs, centrality, distances, and other technological advances analysis of the patents domain being captured. These analytical tasks are mainly: 1) classification (categorizing patents to classes and subclasses); 2) retrieval (which patents come up in a search query using various query objectives); 3) visualization (summarizing patent information graphically); and 4) valuation (innovation scoring, infringement decisions).

The project can evolve in the direction of interest of the PhD candidate. Possible directions are:

a) Enriching the existing database by natural processing tool that captures the existing functional analysis diagrams for mechanical patents in public domain patents databases.
b) Generalising the ontology to other higher levels, or specifying to lower levels, and verifying the model built.
c) Add more network analysis methods and machine learning techniques to identify patterns, trends, and improve the similarity scoring.

2. Modelling a genetic disease using network dynamics

Key words: Bioinformatics, Network Dynamic Modelling,

The human body cells are ongoing a continuous cycle of dynamics based on the inherited genetic code, interactions with the environment that changes the concentrations of mRNAs and proteins and hence the functions they perform on a time domain. Modelling a genetic disease as a dynamic network of agents representing the current cell concentrations of mRNAs and proteins and how they interact together with signals coming from the environments (some are noise and perturbations, and some are enzymes from drugs or foods among others) as complex system is one approach. Another approach is to design a robust synthetic gene network and apply Linear Matrix Inequality (LMI) to fine tuning network parameters to reach the desired state. Modelling one or both approaches or others on a case study of a disease or more and compare results can provide more insights and built useful tools.

3. Multimodal Deep learning Using various Approaches and case studies.

Key words: Multimodality, Deep Learning, Data Fusion, Tensor Computation

Deep learning builds different heterogenous models for various applications such as image analysis, text mining, audio signal analysis and wide range of applications. Each model has different dimensionality, and different analysis functions. The human brain performs all these functions and on top of that, performs a binding step applying data fusion between the outcome of these multimodal identifying the intermodality and cross-modality information. Various approaches have been applied based on the Deep Belief Net (DBN), Stacked Auto Encoder (SAW) based, CNN based, and RNN based. There are other approaches such as: Multi-Agent Reinforcement Learning, and Tensor multiway analysis. Building a model for robotics Multisensory integration for the binding problem and multisensory perception to aid the decision making as a case study can be a possible PhD aim. Other scientific computation case studies can be approached as interesting for the PhD candidate.

4. Study Representation Theory relationship to learning theory in the human brain to better build deep learning models.

Keywords: Multimodality, Deep Learning, Data Fusion

In single modal learning from one sensor or activation, a valid representation is required to facilitate the higher levels of abstractions that lead to proper outcome. In multimodal learning, different representations are usually designed for each modal, and a fusion step generates an abstracted representation. Studying the literature of these mechanisms in the human brain and in the artificial neural networks, will enable innovation in the binding step of multisensory integration and multimodal artificial neural networks. A PhD candidate can build a sample tool to simulate the various representations and their formation to different activations, and their integration to an abstract representation, and finally evaluate how the different representations affect the final outcome.

5. Dictionary Learning using Neural Networks for Source Separation

Key words: Deep Learning, Digital Signal Processing, Dictionary Learning

The classical example of a source separation problem is the cocktail party problem, where several people are talking simultaneously in a room, and a listener is trying to follow one of the discussions. The problem has wide range of applications such as: separating the different instruments in a musical audio file, image processing to separate mixed images or eliminate interference such as in medical imaging, EEG and MEG, among others. Various methods have been applied such as: NMF, Multivariate Analysis including Independent Component Analysis (ICA), Duet algorithm, Sparse Component Analysis, Dictionary Learning and Deep learning methods such as CNN and RNN models. A combination of dictionary learning, and deep learning models can be investigated to build a better understanding of each source in various problems. A possible thesis objective would be to make a deep neural network (probably CNN) to learn the dictionary bases for the different musical instruments sources to use in decomposing a mixture of music signals. The literature provide rich Datasets, Tasks, and Evaluation Procedures such as those from community-based Signal Separation Evaluation Campaign (SiSEC 2018): Professionally produced music recordings, and Asynchronous recordings of speech mixtures.