Research Statement
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Adaptive decision support: New informatics paradigms in a changing world
Real-world problems are complex, uncertain, and changing. Decision making in many critical areas in biomedicine and health care, including managing influenza epidemics, designing personalized medicine, engineering devices to help the aged, etc., are often complicated by the incomplete information, interacting factors, evolving conditions, and limited resources. These problems require adaptive and cost-effective solutions grounded on computational and communication technologies that can effectively manage “change.”

For example:

- A new influenza outbreak caused by a new strain of virus, e.g., the recent H7N9, may have complex transmission patterns and varying severity depending on the location, age, gender, and living habits of the infected individuals. How can management guidelines be adapted to the different populations, across nations and over time?
- For a chronically ill patient with an acute complication, the physiological state of the patient may deteriorate over a period of time with different rates. How can a diagnostic test or treatment protocol be adjusted for different patients at different times?
- To understand the cell-signaling networks in cancer, limited information is gathered from biological knowledge, literature evidences, and experimental results at different stages of the process to reveal the patterns of cell communications. How can personalized drugs aimed at stopping cancer growth be designed to target such emergent patterns?

My long-term research aims at harnessing insights from the integrative discipline of brains, minds, and machines, at the intersection of neuroscience, cognitive and behavioral science, and artificial intelligence to develop new computing and information technologies to improve the quality of life and happiness for humankind.

My research focuses on inventing new techniques and systems for solving real-life decision problems where the domain factors and action effects change over time. These problems are motivated by and tested in a wide range of biomedical and health care settings – from understanding biological processes and systems, to improving patient care at the bedsides, and analyzing epidemiological policies and plans in cancer, heart disease, respiratory disease, head injury, stroke, dementia and other conditions. I have worked on applications that span from genes, organs, individuals, to populations and societies, relevant to the emerging and fascinating areas of social neuroscience. Other focus areas include human-friendly robotics, game artificial intelligence, and personalized education.

Working together with collaborators, staff and students at the Medical Computing Laboratory of the School of Computing (SoC), National University of Singapore (NUS), where I am currently on leave from, I have developed new methodologies for predictive modeling, outcome analysis, risk management, decision analysis, and scenario planning in a wide range of decision tasks. The resulting frameworks facilitate cost-effective diagnostic, therapeutic, and prognostic management, policy and technology evaluation, and personalized medicine in various chronic and critical care domains. My work continues at the School of Information Systems (SIS) of the Singapore Management University (SMU).
My current research concentrates on two main themes: knowledge discovery and learning from real-world datasets, with focus on handling mixed, noisy, and sparse data; and reasoning with change, with emphases on managing and representing change. The application domains span from detecting emerging patterns in cell signaling networks, to intelligent image-based diagnosis in strokes and brain injuries, and decision support using personal health systems for managing regional liver transplant patients. Challenges in intelligent games and robotic navigation, with potential impact on assistive, automated care, are explored as well.

**Toward a paradigm shift:**

This line of research aims at inducing a paradigm shift in medical and health decision support, leading to future adaptive systems that are sustainable and cost-effective. These systems will grow or evolve with changes in the technical functionalities, system infrastructures, and usage patterns.

My overall approach is to directly tackle complex issues in the real-life, hard problems. While the work so far has focused on the theory and methodology, the initial results are tested on real biomedical and health care domains; translational research will commence soon.

1. **Learning with real-world data – imbalanced, multimodal, and unlabeled or incomplete**

   We have proposed a new, model-driven sampling approach to balancing data samples in the classification of mild and severe head injuries. This approach extends the idea of generative sampling to produce new data points based on an induced probabilistic graphical model [1]. This work has identified the challenges in imbalanced data problems in biomedicine, and highlighted the strengths and limitations of the relevant sampling approaches.

   We have developed techniques to learn from multimodal information to predict coronary artery disease with phenotype information and genetic markers, derived both from data and expert opinions [2]. We have also investigated learning from multiple databases – free text, structured, and numerical databases for automated formulation for identifying functional patterns in protein-protein interactions.

   Our recent work in imaging informatics focuses on identifying abnormalities and diseases from scarcely labeled and poorly segmented brain images. We have developed an unsupervised, non-parametric technique for automated pathology annotation that can significantly reduce the time and effort for data labeling and system calibration in large medical image repositories. We proposed both generative [3] and discriminative [4] probabilistic approaches, with an automated feature selection method based on sparse group lasso, to classify images according to the varying availability of expert knowledge and labeled training data. We improved the adaptability of the annotation systems by combining unsupervised feature extraction with case-based classification in an ensemble learning framework [5]. We also combined both image and structured data with text mining from radiology reports for diagnostic and prognostic prediction of head injury patients [6] [7]. Translational efforts in this line of work have begun to deploy the open source tools in actual clinical and teaching environments.

2. **Managing change - Context-sensitive reasoning, active and transfer learning**

   We have introduced a new representation, context-sensitive networks (CSNs) that can dynamically adapt to specific contexts as new evidence arrives. CSNs support focused reasoning and learning with incomplete and changing information [8]. We are extending context-depending reasoning capabilities into partially observable, temporal relational models. We are also investigating how to factorize large, complex decision models into hierarchical [9] and minimal models [10] for supporting efficiency solution and analysis.

   We are examining how to learn relevant information in changing environments by actively directing what to learn and transferring learned knowledge from one problem domain to another. We have developed active learning techniques that introduce specific interventions to
support hypothesis generation and verification with sparse data in biological experiments [11] [12]. We have designed an efficient, online framework that, through a sequence of tasks, learns a set of relevant representations to be used in future tasks. We have demonstrated the potential impact of this general approach to transfer learning across different environments with different world dynamics, e.g., for a robot nurse to work outside the patient’s home [13]. We are also developing a hierarchical approach to reinforcement learning through a novel way of decomposing a complex problem into a set of tasks at different levels of abstraction, each of which can be easier to solve.

3. Representing change – intention recognition and representation discovery

Traditional learning approaches usually assume stationary problem characteristics, which do not reflect the dynamically changing conditions in real-world environments. We have developed a set of techniques for detecting dynamic changes or intentions in the collaborative decision making [14] [15]. We have investigated how to use randomized heuristics based on Monte Carlo tree search to estimate the “goodness” of solution policies in large, complex decision problems for intention recognition in intelligent games [16] [17].

We adopt a flexible “representation generation” approach to accommodate the changing environment. We have experimented with different graphical models for supporting knowledge discovery [18] We have also proposed a new framework for learning the world dynamics of feature-rich environments online through action effects. We have derived theoretical guarantees and empirically demonstrated its practicality in both simulated and real robotics domains [19]. The results are promising for building care or assistive robot nurses that can learn new tasks while attending to more “routine” responsibilities, and operate in new and unfamiliar environments. Translational research for this set of open source tools in elderly care robotics is being planned.

4. Toward an intelligent framework for supporting community and home care decision making for dementia management

My most recent research is on developing fundamental technologies and practical systems to support the full spectrum care management of dementia patients. In collaboration with local health care organizations, academic collaborators, and potential technology partners, we are developing techniques for diagnosing and staging dementia from multimodal information [20], integrating time-varying patient models with cognitive and probabilistic approaches, and designing care assistance robots that can learn and adapt to care for the patients according to disease progression, behavioral sensing, and interactive feedback.

Selected Recent Publications


