RESEARCH STATEMENT
The Intelligence Layer: Robust Decision-making via AI and Machine Learning
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The Past and The Present
The next technological revolution in computing is the intelligence layer and it is rapidly taking shape:

- Thanks to Google, Facebook, and Twitter, the Internet is transforming from a passive repository of text to an active real-time recommender of localized, personalized, and socially-aware media;
- Thanks to the iPad, the Wii, and the Kinect, our children will view keyboards like we view punch cards — our days of reformulating typed queries and scrolling through result lists are numbered;
- Thanks to improved sensors, networking, and coordinated actuation, transport systems that affect billions of lives daily are becoming more aware and more adaptive — saving time and emissions.

What do Internet search, device interaction, and automated transport have in common? Intelligent decision-making! Search engines must decide what content to recommend to you, interactive devices must present information and decide on your interaction intent to manipulate it, and transport systems must fuse information from thousands of sensors to decide how to best improve traffic flow for society.

My research focuses on intelligent decision-making that enables these technologies, with applications ranging from interactive recommendation systems to next-generation traffic control. This work involves artificial intelligence (AI) and machine learning, with emphasis on the following:

- (Bayesian) probabilistic modeling and inference in graphical models;
- sequential decision-theory: MDPs, POMDPs and their reinforcement learning extension;
- parametric and non-parametric (kernel) learning;
- logical knowledge representation and reasoning; and
- (convex) optimization — as a fundamental tool underlying much of my work.

Despite the diversity of these AI and machine learning subfields, they all form integral representation, reasoning, and learning components in intelligent and robust decision-making systems. My research ranges from the theoretical components of these systems through to the end applications.

Following is a survey of the ABCs of my research (or rather, BDLRSs) spanning the above areas of AI and machine learning that support the intelligence layer in a variety of decision-making applications.

B: Bayesian on a Budget

Bayesian (graphical) models provide a natural way to represent uncertainty in the world. These models are especially robust to noise and overfitting and easily accommodate missing or partial data. Historically, Bayesian models have been impractical for applications due to the computational complexity of inference, but this has been notably changing in recent years with the introduction of efficient Gibbs MCMC sampling techniques and message passing approximation algorithms like expectation propagation. In budgeted Bayesian learning and decision-making, I design novel Bayesian extensions of online decision-making algorithms like real-time dynamic programming [9], temporal difference learning [10], and preference elicitation [11] to yield the benefits of a Bayesian approach without increasing the computational complexity over non-Bayesian variants of these algorithms.
D: Decision Diagrams on a Diet

One of the most important data structures for efficiently manipulating expressive functions for probabilistic and decision-theoretic inference is the decision diagram. With David McAllester, I defined the Affine Algebraic Decision Diagram (AADD) [2, 3] for compactly representing logical and arithmetic structure in functions. For my thesis work, I developed the first-order ADD (FOADD) [5, 6] for exploiting first-order relational structure in lifted solutions to planning problems. And crucial to my current work on traffic control is a canonical continuous variable extension of the ADD.

L: Language, Logic, and Learning

Many applications involve data in the form of natural language text and logic and learning are often integral components of intelligent decision-making in these text-based applications.

My interest in logic and language stems from an internship with William A. (Bill) Woods at Sun Microsystems Labs, where I built a natural language search system using description logics (DLs). This work led me to Masters research with the Knowledge Systems Lab at Stanford, where I continued my interest in DLs with research on efficient reasoners for the Semantic Web [14].

I returned to text applications when I joined the Document Analysis research project at NICTA headed by Wray Buntine. Here, I have pursued a number of applied text and natural language research projects for NICTA capability demonstrators, using logical inference or machine learning (e.g., Bayesian topic modeling). These projects include interactive visual search, automatic summarization, query expansion, sentiment and opinion analysis, time and event extraction, hierarchical text classification, and question answering; my [CV] contains a full list of these projects and demos.

R: Recommendations under Risk

Bayesian decision theory extends Bayesian modeling to make robust decisions w.r.t. to risk. I apply Bayesian decision theory to human interface tasks ranging from standard information retrieval [12] to interactive (collaborative) recommendation [11, 13], applicable to a variety of media. Bayesian decision-theoretic models also naturally support value of information computations that address the exploration vs. exploitation trade-off — a crucial aspect of active feedback recommendation strategies where it is desired to make near-optimal recommendations with as few interactions as possible.

S: Symbolic Specifications and Solutions

Starting with my PhD research [1] under the supervision of Craig Boutilier and continuing today, I research compact symbolic representations and (approximately) optimal solutions of fully and partially observed sequential decision-making problems (MDPs and POMDPs) with factored [2, 3], relational [4, 5, 6, 7], and continuous state and action spaces — the latter forming the cornerstone of my traffic control research. My research has pushed the boundary of the expressivity of sequential decision-making problems that can be solved optimally or tractably approximated.

As a major contribution to the planning community arising from this research, I have developed the unifying relational dynamic influence diagram language (RDDL) [8] to represent the above decision-making problems. Using RDDL, I will run the ICAPS International Probabilistic Planning Competition (IPPC) where — given the influence of past IPPCs — I intend RDDL to encourage the probabilistic planning field to shift focus to more expressive, symbolically specified problems.

The Future

My vision for the future is simple: social media is connecting all information and linking it to end users, the Internet is becoming more interactive and personalized, and every embedded system
that impacts our lives will become more adaptive. These applications all need robust decision-making — recommendation, search, interaction, transport logistics — and my research in AI and machine learning provides the intelligent decision-making layer that will help bring this vision to life.

References


