Md Mohimenul Kabir
PhD Candidate, National University of Singapore
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My research interest lies in automated reasoning, specifically at the intersection of formal methods and knowledge representation techniques. The goal of my research is to develop scalable, effective and verified automated reasoning systems, with the aim of enhancing trustworthy computing. My research focus also addresses real-world problems by leveraging efficient automated reasoning systems. While current generation of automated reasoning systems are often effective for the qualititive reasoning task (e.g. yes/no answer), these reasoning tasks often suffice for traditions systems that function deterministically. However, modern computing systems require reasoning beyond qualitative answers; quantitative reasoning (the number of combinations that yield yes answer) is crucial to understanding their behavior. My research primarily focuses on engineering advanced automated reasoning techniques capable of handling such complex tasks (e.g. quantitative analysis).

From a technical perspective, my research work focuses on *counting problem* in context of Answer Set Programming (ASP), which is often referred to as *answer set counting* problem. ASP is a promising paradigm in knowledge representation and automated reasoning due to its natural ability to model complex combinatorial problems across diverse domains. To achieve my research goals, I pursue a tight integration of two key research thrusts: engineering **scalable counting techniques** and addressing **real-world applications** exploiting efficient counting techniques. The first research thrust focuses on engineering algorithmic frameworks for counting, supported by rigorous theoretical guarantees, exploiting the success of well-engineered counting and reasoning tools [5, 4]. The second research thrust involves developing algorithmic frameworks aimed at addressing real-world problems, which are often reducible to counting problems, exploiting sound and complete reduction techniques [6, 7, 3].

During my PhD, I collaborated with several institutions, including TU wien (Austria), JKU Linz (Austria), IIT Bombay (India), University of Toronto (Canada), Tec de Monterrey (Mexico) and my undergraduate university BUET. In addition to quantitative analysis, my research collaborations have spanned metaheuristic on transportation network design [9], image constrast enhancement [8], and bioinformatics [10, 1, 2]. My work has been published in leading conferences and journals across fields such as artificial intelligence, logic programming, automated reasoning, bioinformatics, and transportation research: AAAI (2022 and 2024), LPAR (2023), ICLP (2024), TPLP (2024), Bioinformatics (2020), Plos One (2020), TRIP (2022), WALCOM (2018), and NSysS (2024). In total, I have nine peer-reviewed publications (two **A*** and one **A**)[1]. Notably, our paper (a joint work with Kuldeep S Meel) has received the **best paper award** of ICLP 2024. During my PhD, I was awarded with NUS research scholarship (NUS), SoC Research Incentive Award (NUS), IVGS Research award (U of Toronto), and the NUS Student Travel Grants.

I am currently involved in several collaborative projects on qualitative analysis and its applications with esteemed researchers, Kuldeep S Meel (U of Toronto), Supratik Chakraborty (IIT Bombay), Samuel Pastva (Masaryk), Van-Giang Trinh (Marseille), and Yacine Izza (NUS).

Research Thrust 1: Algorithmic Engineering

Counting the number of assignments that satisfy a set of constraints has applications in quantified information flow, computational biology, neural network verification, and related areas, since its capability to address quantitative queries. Answer Set Programming (ASP) is a powerful formalism in knowledge representation and reasoning. Consequently, counting the number of assignments satisfying ASP semantic (i.e., counting answer sets) enables the answering of quantitative queries arising from diverse ASP applications. My research focuses on both exact and approximate answer set counting, supported by theoretical guarantees.

Exact Answer Set Counting: SharpASP Akin to the early days of propositional model counting, state-of-the-art exact answer set counters do not scale well beyond small instances. Exact #SAT-based ASP

[1] CORE Ranking

counters struggle with handling larger input formulas. The primary contribution is a new ASP counting framework, called sharpASP [4], which counts answer sets avoiding larger input formulas. The key idea of counting relies on an alternative way of defining answer sets that allows for the lifting of key techniques developed in the context of propositional model counting. Our extensive empirical analysis demonstrates significant performance gain over current state-of-the-art exact answer set counters.

Approximate Answer Set Counting: ApproxASP Approaches to exact answer set counting are of high worst-case complexity. The primary contribution of this work is the design of ApproxASP [5], the first scalable technique for #ASP that provides rigorous (ε, δ) guarantees. From the technical perspective, we lift the XOR-based hashing framework developed in the context of propositional model counting to ASP. As is witnessed in the development of ApproxMC, designing a scalable counter requires engineering of the underlying ASP solver to handle XOR constraints. To this end, we present the first ASP solver that can natively handle XOR constraints via Gauss-Jordan elimination. Our experimental study demonstrates that ApproxASP can count answer sets for instances that are beyond the capabilities of existing answer set counters.

Research Thrust 2: Solving Real-world Problems via Counting

The second research thrust focuses on bridging real-world computational problems with efficient counting techniques. Specifically, I address these problems by leveraging efficient counting methods.

Network Reliability Estimation: RelNet-ASP We designed a framework, called RelNet-ASP [6], that reduces the problem of network reliability to answer set counting. Our investigations are motivated by the recent progress in the development of efficient answer set counters. The framework RelNet-ASP addresses more general network reliability scenarios and incorporates concepts from weighted model counting. Our empirical evaluation demonstrates that RelNet-ASP significantly outperforms prior state-of-the-art approaches when accounting for both accuracy and runtime performance.

Lower Bounding Minimal Model Count: MinLB The primary contribution of this work is the development of methods for estimating a lower bound on the number of *minimal models* of a given propositional formula [7]. These minimal models are subset-minimal (with respect to set inclusion) models of a Boolean formula. This is achieved by integrating *knowledge compilation* and *hashing-based techniques* with minimal model reasoning, thereby facilitating the estimation of lower bounds. Fundamentally, the proposed methods conceptualize minimal models of a formula as answer sets of an ASP program. Additionally, our methods leverage the efficiency of well-engineered ASP systems.

Future Research Plans

My future research is dedicated to developing efficient, scalable, and verified algorithms and systems for probabilistic inference, automated reasoning, and verification to support robust, reliable, and trustworthy computing systems. Tackling these computational challenges requires both algorithmic advancements and their close integration with computational systems. To achieve these goals, I aim to work in a collaborative environment, gaining insights into real-world challenges and leveraging advances in computer science, to make significant progress in scalable systems for probabilistic reasoning. Below are the key research themes that will guide my work.

Efficient Quantitative Reasoning Systems. The objective is to develope efficient systems for quantitative reasoning, by combining algorithmic improvements, application-specific heuristic, tight intergration between systems and implementations. While counting is an fundamental problem in computer science, its applicability in real-world settings remains in a nascent stage. I aim to persue the research in two research directions: (i) *engineering scalable counting techniques for theories* and (ii) *solving real-world problems using* *scalable counting techniques.* For example, I aim to perform quantitative reasoning over probabilistic answer set programs and answer set programs with weight rules. By advancing research in these two directions, I envision to design scalable quantitative reasoing systems with the goal of achieving significant practical impacts.

Trustworthy Automated Reasoning. Automated reasoning has become increasingly powerful over the past few decades, driven by significant algorithmic breakthroughs and advancements in engineering. However, to trust these systems, it is essential to verify the correctness of these tools. The objective is to formally establish the correctness of automated reasoning systems. For example, I aim to formally verify the correctness of existing ASP systems.

Neurosymbolic AI. Neurosymbolic AI refers to AI systems that aim to combine deep learning methods with symbolic reasoning approaches to enhance the performance of deep learning techniques. Deep learning techniques leverage the strengths of machine learning, while symbolic reasoning techniques rely on rule-based logic. The goal is to bridge these two approaches to address real-world problems effectively through the combined perspectives of machine learning and symbolic reasoning. For instance, I aim to develop a machine learning framework that benefits from the reasoning capabilities of symbolic logic.

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