CAREER: Scaling Up First-Order Logical Reasoning with Graphical Structure

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Project Summary

Criterion 1: What is the intellectual merit and quality of the proposed activity? The ability to represent and reason about objects and relations between them is central to many approaches and applications in Artificial Intelligence (AI), including common-sense query answering, natural-language processing, planning, and diagnosis problem solving. In recent years the number of objects and relations that applications need to consider has increased dramatically, and current real-world applications require reasoning mechanisms that can scale to thousands and more objects and relations. Traditional approaches to logical reasoning that focus on propositional theories are impractical for such real-world domain because propositional representations of the associated theories have explosive sizes, rendering inference useless. On the other hand, current inference in First-Order Logic (FOL) is impractical here as well because it focuses on mathematical theories that are much smaller and lack the structure of real-world common-sense domain theories.

This proposal outlines a challenging career development plan that focuses on scaling up inference over FOL with graph-based structures that are available in real-world domains. In this research the PI will focus first on inference in FOL, and then apply the insights he gains from general FOL to inference with first-order structure on more specialized scenarios (most times avoiding general FOL inference while still using the same structure). The PI is uniquely qualified to do this because of (1) his work on speeding up FOL and propositional inference using partitions of predicate symbols [AM00, AM05], (2) his work on AI-planning using partitions of actions [AE03], (3) his research on optimization algorithms [Ami01, AKR03], and (4) his work on relational probabilistic methods in AI [dSBAR05].

The key idea in this approach is a methodology for inference in FOL that can ignore most interactions between objects, functions, and predicates, and be fast and correct. In this methodology, a given theory is first partitioned into a tree of subtheories, according to different measures of efficiency that depend on the target inference algorithm.

The proposed research starts with creating a theory of such structures in FOL knowledge bases, anticipating future use of the graph structures by inference algorithms. It then considers two paradigms for inference: one in which we use the structure to create compact propositional encodings of the original theory, and one in which inference is carried out directly in FOL guided by the graph structure. In a complementary effort, the proposed research will develop algorithms that partition a given theory automatically according to different optimization criteria that match the target inference algorithm.

Criterion 2: What are the broader impacts of the proposed activity? This project will impact society and daily life with foreseen applications such as: (a) *object detection using computer vision* (e.g., using PRMs that relate low-level features with higher-level objects and concepts), leading to improved security in airports and the workplace; (b) *reasoning with meanings of natural language text* (e.g., matching meanings using FOL, PRMs, and common-sense information), enabling complex queries on text sources; and (c) *Autonomous agents that use common-sense knowledge*, enabling, e.g., blind-leading robot guides, and sophisticated simulations of living beings.

The research will create collaborations between the research disciplines of statistical and logical reasoning, and also between decision making and formal methods. It will produce software tools (graph manipulation, inference software, automated reasoning in multi-user virtual worlds) that will contribute to a lively and interactive education on artificial intelligence, and will be relevant to a broad set of people outside academia. The PI will publish the research results in the most significant journals and conferences as appropriate, and later also in public media and public spaces.

The PI already involves graduate and undergraduate students from minority groups in research. He will continue so, and will support and encourage students to conduct research early on and participate in top conferences. The PI will develop course material that is at the frontier of research, engaging the students in the class with research activities.