Long-Term Declarative Memory for Generally Intelligent Agents

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Abstract

The goal of my research is to develop and evaluate long-term declarative memory mechanisms that are effective and efficient across a variety of tasks.

Introduction

Modern artificially intelligent agents are single-purpose and have difficulty adapting to changes in their environment or assigned problem. There is evidence that extending an agent's cognitive architecture with long-term memory supports broadly applicable and functional cognitive capabilities (Nuxoll and Laird 2007); however, maintaining and querying large stores of knowledge in a task-independent fashion poses significant computational challenges that currently make it impossible to apply agents to real-world problems (Douglass, Ball, and Rodgers 2009).

My thesis research aims to better understand the cognitive proficiencies made possible by endowing agents with long-term memory that computationally scales to large stores of declarative knowledge. This work is critical to the development of computational agents, such as autonomous robots, that persist for long periods of time, robustly contending with, and continually improving performance on, multiple, complex problems, such as personal caregiving, search-and-rescue, and long-term autonomous exploration in dangerous environments.

Research Plan

I plan to undertake a principled computational exploration of two highly functional, human-inspired, long-term memory systems, semantic and episodic. According to psychological literature (Tulving 1983), semantic memories include general facts the agent "knows," independent of the context in which they were originally learned. In contrast, episodic memories reflect autobiographical, contextualized experience, which allow an agent to "remember" its own past.

I focus on the computational challenges involved in endowing agents with these memory systems by implementing, formally analyzing, and empirically evaluating novel data structures and algorithms that are efficient for real-world tasks, even as the amount of knowledge the agent experiences grows very large.

I also plan to devise evaluation strategies for researchers to compare task-independent, long-term memory models, including the development of novel software benchmarks and experimental domains.

Progress

My work to date has focused on developing and evaluating task-independent episodic and semantic functionality that scales with large bodies of knowledge.

Episodic Memory

Episodic memory, though seemingly crucial to human reasoning, has largely been absent from artificially intelligent agents (Nuxoll and Laird 2007). We have studied episodic functionality in context of three core operations: (1) automatically *encoding* agent state, represented as a connected graph, and storing this information as episodic agent knowledge; (2) *cue matching*, which identifies the best matching prior episode in response to an agent query; and (3) *reconstructing* episodic knowledge to facilitate agent reasoning.

We have found that in general, maintaining bounded episodic processing as the agent contends with multiple, complex tasks over long lifetimes presents a significant computational challenge (Laird and Derbinsky 2009). However, we have developed system-independent data structures and algorithms that, in practice, perform fast enough for real-time task performance, with relatively moderate storage requirements. We have implemented our methods within the Soar cognitive architecture (Laird 2008) and evaluated agents on a tile-based competitive tank game (Derbinsky and Laird, 2009), as well as a high-fidelity robotic simulation of building exploration and clearing operations (Laird, Derbinsky, and Voigt 2011).

Future Work. In my work to date I have assumed that episodic retrievals are biased only by temporal recency. I plan to explore additional contextual features, such as emotional appraisal, that may enhance retrieval quality across numerous tasks, as well as the feasibility of computationally scaling these biases to large stores of episodic agent experience.

Semantic Memory

Unlike episodic memory, semantic memory functionality has been widely applied in the cognitive architecture and cognitive modeling communities (Langley, Laird, and Rogers 2009), though the computational challenges of efficiently retrieving semantic knowledge from large declarative stores has gone largely unstudied.

We have formulated and analyzed the computational challenges involved with supporting efficient access to large stores of declarative knowledge (Derbinsky, Laird, and Smith 2010). We detail system-independent data structures and algorithms, as implemented within Soar, that support retrievals over very large real and synthetic data sets, including the entirety of the WordNet lexicon of the English language (Miller 1995).

We have also begun an exploration into heuristics that can usefully and efficiently bias semantic retrievals in the case of ambiguous cues (Derbinsky and Laird 2011). We are seeking memory biases that are functionally beneficial across numerous tasks, but have begun our study with the word sense disambiguation task (Navigli 2009), in which an agent must identify the most appropriate word meaning in response to an ambiguous linguistic cue. In this task, we demonstrated the functional benefit of a set of memory retrieval heuristics that incorporate the history of memory access, including base-level activation (Anderson and Schooler 1991), as applied to SemCor (Miller et al. 1993), the largest and most used sense-tagged corpus. We have developed and evaluated system-independent methods to efficiently integrate these retrieval biases within a task-independent long-term memory, as demonstrated in Soar.

Future Work. My work on effective and efficient semantic memory retrieval heuristics has thus far focused on a single linguistic task and historical forms of memory bias. I plan to extend this work to additional domains and investigate methods for efficiently incorporating present context as an additional source of retrieval bias.

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