There is a pot of gold, you just don't see it: Applying Rainbow to partially observable environments

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Abstract

Recent breakthroughs in deep reinforcement learning have led to AI solutions to many previously untenable games and environments. ViZDoom, an interface to the popular first person shooter (FPS) DOOM, is a particularly informative environment because of the partial observability of the state and potential complexity of the actions. This paper details an attempt to apply Rainbow, a reinforcement learning (RL) algorithm combining several improvements to Deep Q-Networks(DQN), to different scenarios within the ViZDoom environment. Preliminary results reveal the difficulty of the environment and offer insights into future directions for improving agent performance.

Introduction

In the past decade, with new access to data and computational power, artificial intelligence (AI) researchers have made enormous strides. Deep learning (DL), a type of machine learning once considered computationally intractable, has revolutionized our approach to many problems. Deep neural networks (DNNs) provide a generalizable alternative to previous domain-specific solutions.

Background

Reinforcement learning (RL) is a method by which some *agent* can learn to act in an unknown *environment* to maximize some goal expressed via *rewards*. RL is unique in that the agent does not need to be told *how* to act; rather, it learns through trial-and-error by encountering rewards as it acts and attempting to choose actions which maximize future rewards.

RL Terminology

The interaction of the agent and the environment is formalized as a Markov Decision Process (MDP). An MDP is defined by a tuple $\langle S, A, T, R, \gamma \rangle$ where:

- S is the set of possible states of the environment
- A is the set of possible actions of the agent
- T is the transition function $T(s, a, s')$ giving the probability of reaching each state s' from state s when taking action t
- R is the reward function $R(s, a)$ giving the reward of taking action a in state s
- γ is a discount factor applied to future rewards

At each timestep $t \in \tau$ (where τ is the end time), the agent takes an action a_t from start state s_t. The state changes to s_{t+1}, and the agent receives an immediate reward r_{t+1}. The agent chooses it's action based on a *policy* $\pi(a_t|s_t)$ which gives the probability of taking action a_t in state s_t. The objective of reinforcement learning is to achieve an optimal policy π^* which maximizes the reward the agent accumulates in the environment (i.e., the *return,* G).

In value-based reinforcement learning, the agent learns π by determining the *Q-value* of its actions, where $Q^\pi(s, a)$ is the expected return of taking action a in state s if the agent chooses future actions based on policy π. It then derives a policy that takes the actions with the highest value, updating values as it encounters rewards.

Large state spaces

One problem with this formalism is computational. In simple environments with few states and actions, an agent can store and calculate each $Q(s, a)$. In more complex environments, however, if the agent is even able to store all possible $Q(s, a)$, the number of actions it must take to accurately calculate them increases exponentially.

This issue can be solved by replacing the tables with DNNs, allowing the agent to learn reduced approximations of policies and values. Specifically, in the original DQN architecture* used for Atari games, the agent has a network that computes the Q-value for any input combination of pixels from the game frames. Training an accurate DQN is data-intensive, but can leverage a *replay buffer* to reuse the agent's experiences and learn *off-policy* (i.e., without taking actions in the environment).

Partial Observability

Another problem with the original formalism is sensory. In most environments, it's unrealistic for the agent to have access to the full state of the environment. Rather, the agent receives *observations* from its sensors in the form of camera images, communications, or other modalities. An extended formalism to capture this is known as a Partially Observable MDP (POMDP). A POMDP is an extended MDP defined by a tuple $\langle S, A, T, R, \Omega, O, \gamma \rangle$, where:

- Ω is the set of possible observations o
- O is the conditional probability function $O(o|s', a)$ specifying the probability of the agent observing o after taking action a and reaching environment state s'

At each timestep $t \in \tau$, the environment is in state s_t, the agent takes action a_t and receives observation $o_t + 1$ and reward $o_t + 1$. The environmental state may change, but the agent doesn't know. Rather, the agent determines a policy either directly from observation $\pi(a_t|o_t)$ or by developing a belief about the state s from its observations ($\pi(a_t|b_t)$ where b_t is a *belief* about the current state).

However, a single observation may not be sufficient to determine an optimal action or belief, so these are often conditioned on some history of actions, observations, and rewards h. Maintaining such a history is itself a problem, since it is difficult to know which experiences are relevant and impossible to store all of them.

Deep Recurrent Q-Networks

One potential solution to this is to approximate the history in the same way that DQN approximated the Q-values. Deep Recurrent Q Networks (DRQNs) are an extension to DQN that incorporate *recurrent* network layers. A recurrent network layer is any layer whose output is conditioned on previous inputs. What outputs are conditioned on is known as the *hidden state* of the layer and serves as an approximate memory.

Thus, by incorporating recurrent layers, a DRQN is able to infer the state from temporally extended inputs, and so its calculated $Q(o, a)$ can more accurately reflect sequences of events. The original DQN approximated this by providing input as a sequence of 4 frames*.

Related Work

The primary motivation behind this paper was Rainbow, a paper which combined several improvements to DQN*. Specifically, Rainbow applies:

- **Double Q-Learning**: Using a target network to reduce maximization bias*
- **Prioritized Replay**: Weighting experiences based on their difference from expected value*
- **Dueling Networks**: Dividing the output of a network into the value of a state and the advantage of taking an action*
- **Multi-step Learning**: Calculating the return of multiple future steps rather than just the immediate reward and expected value of the next state*
- **Distributional RL**: Maintaining a distribution of expected Q-values rather than a single one*
- **Noisy Nets**: Replacing ϵ-greedy exploration (i.e., taking a random action with probability ϵ) with implicit exploration in the form of injected noise during training*

Rainbow and its ablations were tested extensively on the Atari environment in an attempt to determine which improvements made the biggest difference and explain the potential advantages of each. They concluded that prioritized replay and multi-step learning were the most impactful additions, but that the impacts of all the improvements were dependent on the environment chosen. Thus, it would be of interest to see how these improvements interact with more complex, partially-observable environments.

The other motivation was to leverage the VizDoom environment. VizDoom is a doom-based AI research platform specifically tailored to deep reinforcement learning*. As such, it has inspired both an annual AI deathmatch competition* and several papers. Among these is Chaplot and Lample's Arnold, an AI which combines DRQN navigation and DQN shooting and which won the 2017 competition. Arnold forms the primary basis for this paper's AI architecture.

Project Description

This project consisted of 3 main parts.

- Implement the algorithms from Rainbow for a DRQN-based agent
- Develop a scenario in VizDoom
- As in Rainbow, permute which algorithms are used for the agent and observe how the permutation affects training

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Additional Resources

LaTeX is a difficult program to master. If you've used that software, and this document didn't help or some items were not explained clearly, we recommend you read Michael Shell's excellent document (testflow doc.txt V1.0a 2002/08/13) about obtaining correct PS/PDF output on LaTeX systems. (It was written for another purpose, but it has general application as well). It is available at www.ctan.org in the tex-archive.

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Thank you for reading these instructions carefully. We look forward to receiving your electronic files!