Deep Q-Learning with Recurrent Neural Networks

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Abstract

Deep reinforcement learning models have proven to be successful at learning control policies image inputs. They have, however, struggled with learning policies that require longer term information. Recurrent neural network architectures have be used in tasks dealing with longer term dependencies between data points. We investigate these architectures to overcome the difficulties arising from learning policies with long term dependencies.

1 Introduction

Recent advances in reinforcement Learning have led to human-level or greater performance on a wide variety of games (e.g. Atari 2600 Games). However, training these networks can take a long time, and the techniques presented in the state of the art [0] perform poorly on several games that require long term planning. Deep Q-networks learn to estimate the Q-values (long term discounted returns) of selecting each possible action from the current game state.

Deep Q-networks are limited in that they learn a mapping from a limited number of past states, or game screens. In practice, DQN is trained using an input consisting of the last four game screens. Thus, DQN performs poorly at games that require the agent to remember information more than four screens ago. In other words, the game could no longer be modeled as a true Markov decision process; all of the information needed to make an optimal action would no longer be contained in a single state. This is evident from types of games DQN performs poorly at, near or below human-level Figure 1. We explore the concept of a deep recurrent Q-network, a combination of a long short term memory (LSTM) [6] and a deep recurrent Q-network (DRQN) similar to [5]. We wish to demonstrate with the introduction of recurrent network architecture into the deep Q-network, the network can retain information from previous frames of the game and achieve good performance on games that require long term planning.

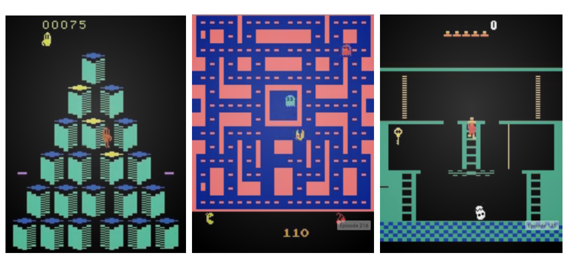

Figure 1: Q*bert, Ms. Pac-Man and Montezuma's Revenge

In addition, recent achievements of attention recurrent neural networks in long term sequence tasks [2, 3] have introduced the possibility of incorporating them into the structure of the DRQN architecture. The advantage of using attention is that it enables DRQN to focus on particular previous states it deems important for predicting the action in the current state. We investigate augmenting

DRQN with attention and evaluate its usefulness.

2 Deep Recurrent Q-Learning

We propose two architectures for the Deep Recurrent Q-Network (DRQN). The first is a very basic extension of DQN. We look at the last L states, $\{s_{t-(L-1)}, \ldots, s_t\}$ and feed these into a convolutional neural network (CNN) to get intermediate outputs $\text{CNN}(s_{t-i}) = x_{t-i}$. These are then fed into a RNN (we use an LSTM for this but it can be any RNN), $\text{RNN}(x_{t-i}) = h_{t-i}$, and the final output h_t is used to predict the Q value.

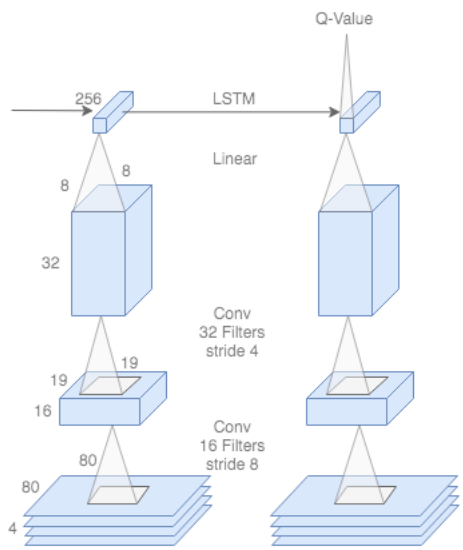

Figure 2: Architecture of the DRQN

Another architecture we used was a version of an attention RNN. For the attention RNN we take the L hidden states outputted by the RNN, $\{h_{t-(L-1)}, \ldots, h_t\}$ and we take the inner product with a learned vector v_a, $\{v_a^T h_{t-(L-1)}, \ldots, v_a^T h_t\}$. We then take a softmax over these values, $a_{t-i} = \text{softmax}(v_a^T h_{t-i})$. We use this softmax to take a weighted sum over the hidden states to get a context vector, $c_t = \sum_{i=0}^{L-1} a_{t-i} h_{t-i}$. This context vector is then used to predict the Q value.

Learning sequences of observations creates some difficulty when sampling experiences and using the following loss function [0]:

$$L_i(\theta_i) = \mathbb{E}_{e_t \sim U(D)}\left[\left(r_t + \gamma \max_{a'_t} Q(s_{t+1}, a'_t; \theta_i^-) - Q(s_t, a_t; \theta_i)\right)^2\right]$$

where $e_t = (s_t, a_t, r_t, s_{t+1})$, $D_t = \{e_1, \ldots, e_t\}$, γ is the discount factor and $e_t \sim U(D)$ are drawn uniformly at random from the pool of stored experiences. We propose a simple solution where we sample $e_t \sim U(D)$ and then take the previous L states, $\{s_{t-(L+1)}, \ldots, s_t\}$ and zero out states from previous games. For example if s_{t-i} was the end of the previous game then we would have states $\{\mathbf{0}, \ldots, \mathbf{0}, s_{t-(i+1)}, \ldots, s_t\}$ and similarly for the next state $\{\mathbf{0}, \ldots, \mathbf{0}, s_{t-(i+1)}, \ldots, s_{t+1}\}$.

3 Experiments

For our experiments, we chose to play the game Q*bert. We chose Q*bert because it is a challenging game for DQN, which achieved scores only slightly above human-level [0]. However, it wasn't so challenging that DQN could not make any progress, versus a game such as Montezuma's Revenge [0].

For input, the RNN-CNN network takes 4 80×80 preprocessed game screen images. (We will experiment with a reduced state space of 3 or 2 game screens in the future to show that reducing the state space does not degrade performance). The first hidden layer convolves 16 19×19 filters with stride 8 across the input image and applies a rectifier nonlinearly. The second hidden layer convolves 32 8×8 filters with stride 4, again followed by a rectifier nonlinearily. Convolutional outputs are fed to the fully connected LSTM layer. Finally, a fully connected linear layer outputs a Q-value for each possible action.

Episodes are selected randomly from the replay memory and updates begin at the beginning of the episode and proceed forward through time to the conclusion of the episode. The targets at each time step are generated from the target Q-network. The RNN's hidden state is carried forward throughout the episode.

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