Deep Q-Learning for Rubik's Cube

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Abstract

Deep Q-Learning is an algorithm that involves Q-Learning (well known Reinforcement Learning algorithm) and Deep Learning that have proved to be extremely succesfull for some applications (reference here). The Rubik's Cube is a solved game as there exists an algorithm that solves any suffled cube in the minimum number of moves, however we have applied a Deep Q-Learning algorithm to try to solve the Rubik's cube game. Because the reward is positive only when the cube is solved ans that the exploration grows exponentially, we have considered some tweaks for the algorithm such as curriculum learning. Mixed results have been obtain because of the slow convergence of the Q-learning algorithm.

1 Introduction

From a Reinforcement Learning (RL) perspective, the Rubik's Cube game is hard because the reward is always zero, unless the cube is finished (same color on same face) which is a very improbable event if random moves are being taken from a suffled cube. Such situations are almost impossible to solve for classical Q-learning algorithms.

Here we consider a Deep Q-Learning algorithm that is a variant of the Q-Learning algorithm that uses a Feedforward Neural Network at the action-value function to be learned. Our hope is that the network learns patterns in the colors and the action in order to make possible the learning.

Moreover, we want to help the learning by showing easy examples first (cubes almost finished) and the increase the complexity of the examples until we reach the general problem of a completely randomly shuffled cube. Such an approach is knows as Curriculum Learning (reference here).

2 Deep Q-learning algorithm

In this section, we present the algorithm we have used and some theoretical considered aspects.

2.1 Q-Learning

Q-learning is a model-free reinforcement learning technique. It works by learning an action-value function that eventually gives the expected utility of taking a given action in a given state and following the optimal policy thereafter. In our case, the action-value function is a mapping between the combination of the state and the action taken, and the utility value, where the utility value is the sum of the present reward and the discounted future rewards. When the mapping is learned, the optimal policy is to simply select the action that has the highest value in each state.

2.2 Deep Learning

The main specificity about Deep Q-Learning is that the action-value function is a feedforward neural network. The input of the network is a vector representing the state and the action taken and the

output is the utility value. Feedforward neural networks have several advantages. First, they can approximate arbitrarily well any continuous function thanks to the universal approximation theorem (reference here). Moreover, the training on the parameters of feedforward neural networks has been made easy thanks to the backpropagation algorithm (reference here).

2.3 The Deep Q-Learning algorithm in (reference here)

3 Experiments

python theano blocks

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Indicate footnotes with a number[1] in the text. Place the footnotes at the bottom of the page on which they appear. Precede the footnote with a horizontal rule of 2 inches (12 picas).[2]

5.3 Figures

All artwork must be neat, clean, and legible. Lines should be dark enough for purposes of reproduction; art work should not be hand-drawn. The figure number and caption always appear after the

[1] Sample of the first footnote

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Table 1: Sample table title

PART	DESCRIPTION
Dendrite	Input terminal
Axon	Output terminal
Soma	Cell body (contains cell nucleus)

figure. Place one line space before the figure caption, and one line space after the figure. The figure caption is lower case (except for first word and proper nouns); figures are numbered consecutively.

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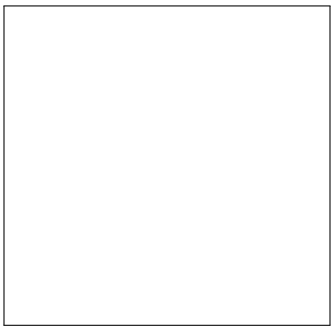

Figure 1: Sample figure caption.

5.4 Tables

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Place one line space before the table title, one line space after the table title, and one line space after the table. The table title must be lower case (except for first word and proper nouns); tables are numbered consecutively.

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Do not change any aspects of the formatting parameters in the style files. In particular, do not modify the width or length of the rectangle the text should fit into, and do not change font sizes (except perhaps in the **References** section; see below). Please note that pages should be numbered.

7 Preparing PostScript or PDF files

Please prepare PostScript or PDF files with paper size "US Letter", and not, for example, "A4". The -t letter option on dvips will produce US Letter files.

Fonts were the main cause of problems in the past years. Your PDF file must only contain Type 1 or Embedded TrueType fonts. Here are a few instructions to achieve this.

- You can check which fonts a PDF files uses. In Acrobat Reader, select the menu Files>Document Properties>Fonts and select Show All Fonts. You can also use the pro-

gram `pdffonts` which comes with `xpdf` and is available out-of-the-box on most Linux machines.

- The IEEE has recommendations for generating PDF files whose fonts are also acceptable for NIPS. Please see `http://www.emfield.org/icuwb2010/downloads/IEEE-PDF-SpecV32.pdf`
- LaTeX users:
  - Consider directly generating PDF files using `pdflatex` (especially if you are a MiKTeX user). PDF figures must be substituted for EPS figures, however.
  - Otherwise, please generate your PostScript and PDF files with the following commands:

    ```
    dvips mypaper.dvi -t letter -Ppdf -G0 -o mypaper.ps
    ps2pdf mypaper.ps mypaper.pdf
    ```

    Check that the PDF files only contains Type 1 fonts.
  - xfig "patterned" shapes are implemented with bitmap fonts. Use "solid" shapes instead.
  - The `\bbold` package almost always uses bitmap fonts. You can try the equivalent AMS Fonts with command

    ```
    \usepackage[psamsfonts]{amssymb}
    ```

    or use the following workaround for reals, natural and complex:

    ```
    \newcommand{\RR}{I\!\!R} %real numbers
    \newcommand{\Nat}{I\!\!N} %natural numbers
    \newcommand{\CC}{I\!\!\!\!C} %complex numbers
    ```
  - Sometimes the problematic fonts are used in figures included in LaTeX files. The ghostscript program `eps2eps` is the simplest way to clean such figures. For black and white figures, slightly better results can be achieved with program `potrace`.
- MSWord and Windows users (via PDF file):
  - Install the Microsoft Save as PDF Office 2007 Add-in from `http://www.microsoft.com/downloads/details.aspx?displaylang=en&familyid=4d951911-3e7e-4ae6-b059-a2e79ed87041`
  - Select "Save or Publish to PDF" from the Office or File menu
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  - To produce the ps file, select "Print" from the MS app, choose the installed AdobePS printer, click on "Properties", click on "Advanced."
  - Set "TrueType Font" to be "Download as Softfont"
  - Open the "PostScript Options" folder
  - Select "PostScript Output Option" to be "Optimize for Portability"
  - Select "TrueType Font Download Option" to be "Outline"
  - Select "Send PostScript Error Handler" to be "No"
  - Click "OK" three times, print your file.
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7.1 Margins in LaTeX

Most of the margin problems come from figures positioned by hand using `\special` or other commands. We suggest using the command `\includegraphics` from the graphicx package. Always specify the figure width as a multiple of the line width as in the example below using .eps graphics

```
\usepackage[dvips]{graphicx} ...
\includegraphics[width=0.8\linewidth]{myfile.eps}
```

or

```
\usepackage[pdftex]{graphicx} ...
\includegraphics[width=0.8\linewidth]{myfile.pdf}
```

for .pdf graphics. See section 4.4 in the graphics bundle documentation (`http://www.ctan.org/tex-archive/macros/latex/required/graphics/grfguide.ps`)

A number of width problems arise when LaTeX cannot properly hyphenate a line. Please give LaTeX hyphenation hints using the `\-` command.

Acknowledgments

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References

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[1] Alexander, J.A. & Mozer, M.C. (1995) Template-based algorithms for connectionist rule extraction. In G. Tesauro, D. S. Touretzky and T.K. Leen (eds.), *Advances in Neural Information Processing Systems 7*, pp. 609-616. Cambridge, MA: MIT Press.

[2] Bower, J.M. & Beeman, D. (1995) *The Book of GENESIS: Exploring Realistic Neural Models with the GEneral NEural SImulation System.* New York: TELOS/Springer-Verlag.

[3] Hasselmo, M.E., Schnell, E. & Barkai, E. (1995) Dynamics of learning and recall at excitatory recurrent synapses and cholinergic modulation in rat hippocampal region CA3. *Journal of Neuroscience* **15**(7):5249-5262.