[[1]](#footnote-1)

Building Poker Bot with Reinforcement Learning (December 2020)

László Barak, Mónika Farsang, Ádám Szukics

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*Impact Statement* — The impact statement should not exceeed 150 words. This section offers an example that is expanded to have only and just 150 words to demonstrate the point. Here is an example on how to write an appropriate impact statement: Chatbots are a popular technology in online interaction. They reduce the load on human support teams and offer continuous 24-7 support to customers. However, recent usability research has demonstrated that 30% of customers are unhappy with current chatbots due to their poor conversational capabilities and inability to emotionally engage customers. The natural language algorithms we introduce in this paper overcame these limitations. With a significant increase in user satisfaction to 92% after adopting our algorithms, the technology is ready to support users in a wide variety of applications including government front shops, automatic tellers, and the gaming industry. It could offer an alternative way of interaction for some physically disable users.

*Index Terms*—poker, reinforcement learning

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# INTRODUCTION

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# Literature review

Poker and Reinforcement learning solutions

Literature Review is needed for the analysis of past studies or scholarly articles to be familiar with research questions or topics. Hence, this section summarizes and synthesizes arguments and ideas from scholarly sources without adding new contributions. In turn, this part is organized around arguments or ideas, not sources.

If you wish, you may write in the first person singular or plural and use the active voice (“I observed that ...” or “We observed that ...” instead of “It was observed that ...”). Remember to check spelling. If your native language is not English, please get a native English-speaking colleague to carefully proofread your paper.

# Methodology

Algorithm and environments

We used RLCard card environments [1] that are designed for reinforcement learning research. It is an easy-to-use toolkit that provides Limit Hold’em and Leduc Hold’em environment. The latter is a simplified version of Limit Texas Hold’em and it was constructed to have a more tractable game [2].

Both types have the same actions: *check, call*, *raise* and *fold*. During *checking* the action passes to the next player without betting. In the case of someone bets, this action is not possible anymore. *Calling* means matching a bet or a raise. If the player chooses to *raise*, he/she increases the size of an existing bet in the round. *Folding* is discarding one’s hand.

The payoff is identical as well in both environments. It is based on the big blinds per hand. The player gets the positive or negative R reward if he/she wins or loses R times the amount of the big blind, respectively.

Limit Hold’em is played with 52 cards. Each player has 2 hole cards and there are 5 community cards with 3 phases, called the *flop*, the *turn* and the *river*. The players have 4 *raise* actions per round each with 4 betting rounds in total. The state representation in this game is a vector of length 72. The first part contains the known cards, namely the hole cards and the already known community cards. The first 13 represents the cards from the Ace of Spade to the King of Spade, followed by the Heart, the Diamond and the Club similarly. The rest of the vector is the number of *raise* actions in each round.

Leduc Hold’em is limited to 6 cards, which are two pairs of King, Queen and Jack. This game is played by 2 players with 2 rounds, where there are 2 *raise* actions in the first one and 4 in the second one. The game is fixed with two-bet and 14 chips maximum.

We implemented a DQN agent in PyTorch. For this, we used the TensorFlow code from RLCard [3] as a base and created a more powerful, more manageable, and easy to use code in PyTorch. This implementation is an advanced Q-learning agent in two aspects. First, it uses a replay buffer to store past experiences, as we simulate the environment and make an action we add the state, action, reward, next state and whether game is done or not, then when we train our network we sample from that replay buffer for a more consistent result. Second, to make the training more stable, another Q-network is used as a target network in order to backpropagate through it and train the policy Q-network. These features were first described in [4].

These networks purpose is to estimate a Q-value given the current state, which can be used to determine which action the agent will take. They consist of a simple neural network with the number of states as it’s input layer and the number of actions as it’s output layer.

Every step the agent first makes an action based on the epsilion value which is responsible for exploration, if epsilion is high the agent is more likely to take a random action if it’s low it will use the Q-network to determine the best action. In the early stages of the game epsilion starts high “exploring” the environment and each step it’s reduced by a small amount to the point when it will be near 0.

The agent learns by sampling a minibatch from the replay memory and gets a Q-value for the next state using the policy network and determines the best action for this state. Then it determines the target Q-value using the target network, calculates the target action using the reward from the replay memory and the target Q-value, then backpropagates using this value.

First the agent will “explore” the environment making random actions and getting positive/negative rewards and updating its Q-network accordingly. But as it plays more and more it will take less random actions and has more accurate Q-values for the given states, playing better and better.

Furthermore, as an extra component, we added the opportunity of a more aggressive playing strategy. In case of the given action has the maximum q-value, the agent chooses the *raise* action as a replacement for it if *raising* is a valid action. Hence, the 3 possible extra settings are to encourage the agent to *raise* instead of *calling*, *checking* and *folding*. We investigate its impact on the performance of the agent.

# Results and Discussion

Hyperparameter optimalization, compare results

In Leduc Hold'em environment, the best mean result comes from the model with 3 layers of 128 neurons each, batch size of 64, 0.99 gamma, 0.1 learning rate, replay memory with size 2000.

. Table

Best performance in Leduc Hold'em

|  |  |  |
| --- | --- | --- |
| strategy | mean reward | reward variance |
| 0 | 0.960 | 0.265 |
| 1 | 1.261 | 0.352 |
| 2 | 0.682 | 0.285 |
| 3 | 0.723 | 0.202 |

In Limit Hold'em environment the best parameter setting is: the best is 2 layers with 128 neurons, 64 batch size, 0.99 gamma, 0.001 learning rate, replay memory size 2000

--> network architecture and learning rate is different

. Table

Performance in Limit Hold'em

|  |  |  |
| --- | --- | --- |
| strategy | mean reward | reward variance |
| 0 | 2.057 | 0.258 |
| 1 | 2.870 | 0.465 |
| 2 | 1.806 | 0.433 |
| 3 | 1.713 | 0.276 |

Discussion is a section of a research paper where scientists review the information in the introduction part, evaluate gained results, or compare it with past studies. In particular, students and scholars interpret gained data or findings in appropriate depth. For example, if results differ from expectations at the beginning, scientists should explain why that may have happened. However, if results agree with rationales, scientists should describe theories that the evidence is supported.

# Conclusions

What findings did we make.

Conclusion includes final claims of a research paper based on findings. Basically, this section covers final thoughts and the summary of the whole work. Moreover, this section may be used instead of limitations and recommendations that would be too small by themselves. In this case, scientists do not need to use headings for recommendations and limitations.



Fig. 1. Magnetization as a function of applied field. Note that “Fig.” is abbreviated. There is a period after the figure number, followed by two spaces. It is good practice to explain the significance of the figure in the caption.

TABLE I

Units for Magnetic Properties

|  |  |  |
| --- | --- | --- |
| Symbol | Quantity | Conversion from Gaussian and  CGS EMU to SI a |
| Φ | magnetic flux | 1 Mx → 10−8 Wb = 10−8 V·s |
| *B* | magnetic flux density,  magnetic induction | 1 G → 10−4 T = 10−4 Wb/m2 |
| *H* | magnetic field strength | 1 Oe → 103/(4π) A/m |
| *m* | magnetic moment | 1 erg/G = 1 emu  → 10−3 A·m2 = 10−3 J/T |
| *M* | magnetization | 1 erg/(G·cm3) = 1 emu/cm3  → 103 A/m |
| 4π*M* | magnetization | 1 G → 103/(4π) A/m |
| σ | specific magnetization | 1 erg/(G·g) = 1 emu/g → 1 A·m2/kg |
| *j* | magnetic dipole  moment | 1 erg/G = 1 emu  → 4π × 10−10 Wb·m |
| *J* | magnetic polarization | 1 erg/(G·cm3) = 1 emu/cm3  → 4π × 10−4 T |
| χ*,* κ | susceptibility | 1 → 4π |
| χρ | mass susceptibility | 1 cm3/g → 4π × 10−3 m3/kg |
| μ | permeability | 1 → 4π × 10−7 H/m  = 4π × 10−7 Wb/(A·m) |
| μr | relative permeability | μ → μr |
| *w, W* | energy density | 1 erg/cm3 → 10−1 J/m3 |
| *N, D* | demagnetizing factor | 1 → 1/(4π) |

Vertical lines are optional in tables. Statements that serve as captions for the entire table do not need footnote letters.

aGaussian units are the same as cg emu for magnetostatics; Mx = maxwell, G = gauss, Oe = oersted; Wb = weber, V = volt, s = second, T = tesla, m = meter, A = ampere, J = joule, kg = kilogram, H = henry.

## Types of Graphics

The following list outlines the different types of graphics published in IEEE journals. They are categorized based on their construction, and use of color / shades of gray:

### *Color/Grayscale figures*

### Figures that are meant to appear in color, or shades of black/gray. Such figures may include photographs, illustrations, multicolor graphs, and flowcharts.

### *Line Art figures*

### Figures that are composed of only black lines and shapes. These figures should have no shades or half-tones of gray, only black and white.

### *Author photos*

### Head and shoulders shots of authors that appear at the end of our papers.

### *Tables* Data charts which are typically black and white, but sometimes include color.

## Multipart figures

Figures compiled of more than one sub-figure presented side-by-side, or stacked. If a multipart figure is made up of multiple figure types (one part is lineart, and another is grayscale or color) the figure should meet the stricter guidelines.

## File Formats For Graphics

Format and save your graphics using a suitable graphics processing program that will allow you to create the images as PostScript (PS), Encapsulated PostScript (.EPS), Tagged Image File Format (.TIFF), Portable Document Format (.PDF), or Portable Network Graphics (.PNG) sizes them, and adjusts the resolution settings. If you created your source files in one of the following programs you will be able to submit the graphics without converting to a PS, EPS, TIFF, PDF, or PNG file: Microsoft Word, Microsoft PowerPoint, or Microsoft Excel. Though it is not required, it is strongly recommended that these files be saved in PDF format rather than DOC, XLS, or PPT. Doing so will protect your figures from common font and arrow stroke issues that occur when working on the files across multiple platforms. When submitting your final paper, your graphics should all be submitted individually in one of these formats along with the manuscript.

## Sizing of Graphics

Most charts, graphs, and tables are one column wide (3.5 inches / 88 millimeters / 21 picas) or page wide (7.16 inches / 181 millimeters / 43 picas). The maximum depth a graphic can be is 8.5 inches (216 millimeters / 54 picas). When choosing the depth of a graphic, please allow space for a caption. Figures can be sized between column and page widths if the author chooses, however it is recommended that figures are not sized less than column width unless when necessary.

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## Color Space

The term color space refers to the entire sum of colors that can be represented within the said medium. For our purposes, the three main color spaces are Grayscale, RGB (red/green/blue) and CMYK (cyan/magenta/yellow/black). RGB is generally used with on-screen graphics, whereas CMYK is used for printing purposes.

All color figures should be generated in RGB or CMYK color space. Grayscale images should be submitted in Grayscale color space. Line art may be provided in grayscale OR bitmap colorspace. Note that “bitmap colorspace” and “bitmap file format” are not the same thing. When bitmap color space is selected, .TIF/.TIFF/.PNG are the recommended file formats.

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## Using Labels Within Figures

### Figure Axis labels

Figure axis labels are often a source of confusion. Use words rather than symbols. As an example, write the quantity “Magnetization,” or “Magnetization *M*,” not just “*M*.” Put units in parentheses. Do not label axes only with units. As in Fig. 1, for example, write “Magnetization (A/m)” or “Magnetization (Am−1),” not just “A/m.” Do not label axes with a ratio of quantities and units. For example, write “Temperature (K),” not “Temperature/K.”

Multipliers can be especially confusing. Write “Magnetization (kA/m)” or “Magnetization (103 A/m).” Do not write “Magnetization (A/m) × 1000” because the reader would not know whether the top axis label in Fig. 1 meant 16000 A/m or 0.016 A/m. Figure labels should be legible, approximately 8 to 10 point type.

### Subfigure Labels in Multipart Figures and Tables

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## File Naming

Figures (line artwork or photographs) should be named starting with the first 5 letters of the author’s last name. The next characters in the filename should be the number that represents the sequential location of this image in your article. For example, in author “Anderson’s” paper, the first three figures would be named ander1.tif, ander2.tif, and ander3.ps.

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Appendix

Appendixes, if needed, appear before the acknowledgment.

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References

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1. Daochen Zha, Kwei-Herng Lai, Yuanpu Cao, Songyi Huang, Ruzhe Wei, Junyu Guo and Xia Hu, “RLCard: A Toolkit for Reinforcement Learning in Card Games,” 2020, [Online]. Available: arXiv:1910.04376.
2. Finnegan Southey, Michael P. Bowling, Bryce Larson, Carmelo Piccione, Neil Burch, Darse Billings and Chris Rayner, “Bayes' Bluff: Opponent Modelling in Poker,” 2012, [Online]. Available: arXiv:1207.1411
3. DATA Lab at Texas A&M University (2020) RLCard [Source code]. <https://github.com/datamllab/rlcard>
4. V. Mnih, K. Kavukcuoglu, D. Silver, “Human-level control through deep reinforcement learning,” *Nature* 518, 529–533, Feb. 2015.
5. W.-K. Chen, *Linear Networks and Systems.* Belmont, CA, USA: Wadsworth, 1993, pp. 123–135.

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J. K. Author, “Name of paper,” *Abbrev. Title of Periodical*, vol. *x, no*. *x,* pp*. xxx-xxx,* Abbrev. Month, year, DOI. 10.1109.*XXX*.123456.

*Examples:*

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2. E. P. Wigner, “Theory of traveling-wave optical laser,”   
   *Phys. Rev*.,   
   vol. 134, pp. A635–A646, Dec. 1965.
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2. J. H. Davis and J. R. Cogdell, “Calibration program for the 16-foot antenna,” Elect. Eng. Res. Lab., Univ. Texas, Austin, TX, USA, Tech. Memo. NGL-006-69-3, Nov. 15, 1987.

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1. G. O. Young, “Synthetic structure of industrial plastics,” in Plastics, vol. 3, Polymers of Hexadromicon, J. Peters, Ed., 2nd ed. New York, NY, USA: McGraw-Hill, 1964, pp. 15-64. [Online]. Available: http://www.bookref.com.
2. *The Founders’ Constitution*, Philip B. Kurland and Ralph Lerner, eds., Chicago, IL, USA: Univ. Chicago Press, 1987. [Online]. Available: http://press-pubs.uchicago.edu/founders/
3. The Terahertz Wave eBook. ZOmega Terahertz Corp., 2014. [Online]. Available: http://dl.z-thz.com/eBook/zomega\_ebook\_pdf\_1206\_sr.pdf. Accessed on: May 19, 2014.
4. Philip B. Kurland and Ralph Lerner, eds., *The Founders’ Constitution.* Chicago, IL, USA: Univ. of Chicago Press, 1987, Accessed on: Feb. 28, 2010, [Online] Available: http://press-pubs.uchicago.edu/founders/

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*Examples:*

1. J. S. Turner, “New directions in communications,” *IEEE J. Sel. Areas Commun*., vol. 13, no. 1, pp. 11-23, Jan. 1995.
2. W. P. Risk, G. S. Kino, and H. J. Shaw, “Fiber-optic frequency shifter using a surface acoustic wave incident at an oblique angle,” *Opt. Lett.*, vol. 11, no. 2, pp. 115–117, Feb. 1986.
3. P. Kopyt *et al., “*Electric properties of graphene-based conductive layers from DC up to terahertz range,” *IEEE THz Sci. Technol.,* to be published. DOI: 10.1109/TTHZ.2016.2544142.

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2. Teralyzer. Lytera UG, Kirchhain, Germany [Online]. Available: http://www.lytera.de/Terahertz\_THz\_Spectroscopy.php?id=home, Accessed on: Jun. 5, 2014

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1. D. Ebehard and E. Voges, “Digital single sideband detection for interferometric sensors,” presented at the *2nd Int. Conf. Optical Fiber Sensors,* Stuttgart, Germany, Jan. 2-5, 1984.

*Basic format for patents:*

J. K. Author, “Title of patent,” U.S. Patent *x xxx xxx*, Abbrev. Month, day, year.

*Example:*

1. G. Brandli and M. Dick, “Alternating current fed power supply,” U.S. Patent 4 084 217, Nov. 4, 1978.

*Basic format**for theses (M.S.) and dissertations (Ph.D.):*

a) J. K. Author, “Title of thesis,” M.S. thesis, Abbrev. Dept., Abbrev. Univ., City of Univ., Abbrev. State, year.

b) J. K. Author, “Title of dissertation,” Ph.D. dissertation, Abbrev. Dept., Abbrev. Univ., City of Univ., Abbrev. State, year.

*Examples:*

1. J. O. Williams, “Narrow-band analyzer,” Ph.D. dissertation, Dept. Elect. Eng., Harvard Univ., Cambridge, MA, USA, 1993.
2. N. Kawasaki, “Parametric study of thermal and chemical nonequilibrium nozzle flow,” M.S. thesis, Dept. Electron. Eng., Osaka Univ., Osaka, Japan, 1993.

*Basic format for the most common types of unpublished references:*

a) J. K. Author, private communication, Abbrev. Month, year.

b) J. K. Author, “Title of paper,” unpublished.

c) J. K. Author, “Title of paper,” to be published.

*Examples:*

1. A. Harrison, private communication, May 1995.
2. B. Smith, “An approach to graphs of linear forms,” unpublished.
3. A. Brahms, “Representation error for real numbers in binary computer arithmetic,” IEEE Computer Group Repository, Paper R-67-85.

*Basic formats for standards:*

a) *Title of Standard*, Standard number, date.

b) *Title of Standard*, Standard number, Corporate author, location, date.

*Examples:*

1. IEEE Criteria for Class IE Electric Systems, IEEE Standard 308, 1969.
2. Letter Symbols for Quantities, ANSI Standard Y10.5-1968.

*Article number in reference examples:*

1. R. Fardel, M. Nagel, F. Nuesch, T. Lippert, and A. Wokaun, “Fabrication of organic light emitting diode pixels by laser-assisted forward transfer,” *Appl. Phys. Lett.*, vol. 91, no. 6, Aug. 2007, Art. no. 061103.
2. J. Zhang and N. Tansu, “Optical gain and laser characteristics of InGaN quantum wells on ternary InGaN substrates,” *IEEE Photon. J.*, vol. 5, no. 2, Apr. 2013, Art. no. 2600111

*Example when using et al.:*

1. S. Azodolmolky *et al.*, Experimental demonstration of an impairment aware network planning and operation tool for transparent/translucent optical networks,” *J. Lightw. Technol.*, vol. 29, no. 4, pp. 439–448, Sep. 2011.

**First A. Author** (M’76–SM’81–F’87) and all authors may include biographies. Biographies are often not included in conference-related papers. This author became a Member (M) of IEEE in 1976, a Senior Member (SM) in 1981, and a Fellow (F) in 1987. The first paragraph may contain a place and/or date of birth (list place, then date). Next, the author’s educational background is listed. The degrees should be listed with type of degree in what field, which institution, city, state, and country, and year the degree was earned. The author’s major field of study should be lower-cased.

The second paragraph uses the pronoun of the person (he or she) and not the author’s last name. It lists military and work experience, including summer and fellowship jobs. Job titles are capitalized. The current job must have a location; previous positions may be listed without one. Information concerning previous publications may be included. Try not to list more than three books or published articles. The format for listing publishers of a book within the biography is: title of book (publisher name, year) similar to a reference. Current and previous research interests end the paragraph.

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**Second B. Author** was born in Greenwich Village, New York, NY, USA in 1977. He received the B.S. and M.S. degrees in aerospace engineering from the University of Virginia, Charlottesville, in 2001 and the Ph.D. degree in mechanical engineering from Drexel University, Philadelphia, PA, in 2008.

From 2001 to 2004, he was a Research Assistant with the Princeton Plasma Physics Laboratory. Since 2009, he has been an Assistant Professor with the Mechanical Engineering Department, Texas A&M University, College Station. He is the author of three books, more than 150 articles, and more than 70 inventions. His research interests include high-pressure and high-density nonthermal plasma discharge processes and applications, microscale plasma discharges, discharges in liquids, spectroscopic diagnostics, plasma propulsion, and innovation plasma applications. He is an Associate Editor of the journal *Earth*, *Moon*, *Planets*, and holds two patents.

Dr. Author was a recipient of the International Association of Geomagnetism and Aeronomy Young Scientist Award for Excellence in 2008, and the IEEE Electromagnetic Compatibility Society Best Symposium Paper Award in 2011.

**Third C. Author, Jr.** (M’87) received the B.S. degree in mechanical engineering from National Chung Cheng University, Chiayi, Taiwan, in 2004 and the M.S. degree in mechanical engineering from National Tsing Hua University, Hsinchu, Taiwan, in 2006. He is currently pursuing the Ph.D. degree in mechanical engineering at Texas A&M University, College Station, TX, USA.

From 2008 to 2009, he was a Research Assistant with the Institute of Physics, Academia Sinica, Tapei, Taiwan. His research interest includes the development of surface processing and biological/medical treatment techniques using nonthermal atmospheric pressure plasmas, fundamental study of plasma sources, and fabrication of micro- or nanostructured surfaces.

Mr. Author’s awards and honors include the Frew Fellowship (Australian Academy of Science), the I. I. Rabi Prize (APS), the European Frequency and Time Forum Award, the Carl Zeiss Research Award, the William F. Meggers Award and the Adolph Lomb Medal (OSA).

1. [↑](#footnote-ref-1)