

# Multi-Agent Reinforcement Learning in Zombie-Survival Games

**Peter Hollows**

stanford@dojo7.com

**Mark Presser**

mark.presser95@gmail.com

## Abstract

The abstract goes here...

## 1 Introduction

Reinforcement Learning (RL) methods are seeing increasing use in real-world control systems. In part, the rising popularity of RL methods is due to its widely publicized success on challenging tasks, as well as the availability of quality open-source frameworks containing implementations of state-of-the-art models.

### 1.1 Closing the Reality Gap

Current RL methods are not sample-efficient, meaning the policy learner needs a lot of data before an effective policy can be found. Often, there is not enough data available, or it cannot be captured safely (consider an autonomous driver learning the best policy for a near-crash scenario, where it will make mistakes in order to learn). To work around these issues, RL policies intended for real-world control tasks are usually trained in simulated environments before being further trained or deployed in the real-world.

However, simulations often do not capture all the relevant real-world dynamics, so it can be difficult to transition a policy from the simulator to reality. This difficulty, known as the "reality gap", is often mitigated by adding noise to the simulation (to mimic noisy sensors and stochastic dynamics), or by sufficiently improving the simulation to model the relevant dynamics.

This approach has enjoyed success in single-agent RL settings like autonomous aircraft and robotics.

### 1.2 Multi-Agent RL

In cooperative settings like factories, or competitive settings like markets, using the simulation

technique becomes more challenging; simulating the dynamics of other agents present in the environment is a difficult problem, even in simulation. This is especially the case when the policies of multiple agents are being modified and improved at the same time.

These issues in multi-agent settings motivated a training algorithm called Multi-Agent Deep Deterministic Policy Gradient (MADDPG). MADDPG addresses some issues in multi-agent learning, and allows running experiments that explore the emergence of policies competitive and cooperative policies in complex environments.

### 1.3 Environmental Dynamics

We explore MADDPG in the context of a mixed competitive-cooperative simulated environment called Zombie-Survival game under multiple scenarios. In these scenarios we show how specific kinds of environmental dynamics can affect large (and sometimes surprising and unintended) changes in the evolution of policies. We present methods and results for each scenario, and conclude with a discussion (??) on safety issues we feel apply to a wide array of RL systems.

### 1.4 Overview

In (2) we review Markov Decision Processes (MDPs), the Actor-Critic algorithm, MADDPG, and agent design. In (3.1) we detail the basic simulation environment. In (3.2) we detail the experimental setup and initial results. In (3.3) we investigate partial observability, and how compression of the observation function can speed policy discovery. In (3.4) we alter the environment to cause a change in the value function (keeping reward unchanged) to study the impact on learned policies. In (3.5) we arm the survivors with projectile weapons to investigate how additional capability can make it harder for agents to achieve their objectives.

## 2 Background

### 2.1 The Markov Decision Process

A Markov Decision Process (MDP) formalizes the interaction of an agent with an environment. At every time step, an *agent* receives observations of the *state* of the *environment*, and sends *actions* to the environment. The environment transitions from one state to the next over time, and actions from the agent can influence which states the environment transitions to. At every time step, the agent receives a *reward* based on the state of the environment. In the case when state transitions are not independent (i.e. the chance of arriving in a state depends on visiting previous states), then agent actions in a state can impact future expected rewards as well as immediate rewards.

RL algorithms attempt to solve the MDP in order to maximize return (reward over time). This can be done by learning a policy (a function that maps from state to action). A policy can often be learned directly, or by learning a value function (a mapping from states and actions to expected returns) from which a policy can be extracted.

### 2.2 Actor-Critic methods

Q-Learning is a popular RL method that makes use of an action-value function  $Q^\pi(s, a)$  corresponding to a policy  $\pi$  (where  $s$  is the state, and  $a$  the action). Deep Q-Learning (DQN) learns the action-value function  $Q^*$  corresponding to the optimal policy by minimizing the loss function

$$\mathcal{L}(\theta) = \mathbb{E}_{s,a,r,s'}[(Q^*(s, a|\theta) - y)^2], \quad (1)$$

where  $y = r + \gamma \max_{a'} \bar{Q}^*(s', a')$ , by repeatedly adjusting the parameters  $\theta$  of the target action-value function  $\bar{Q}$ . The Q-function can be expressed as  $Q^\pi(s, a) = \mathbb{E}[R|s, a]$ , where  $R_t$  is the discounted sum of future rewards at time  $t$ , given by:  $R_t = \sum_{k=t}^{\infty} \gamma(k-t)r_k$ . To reduce the variance of estimates for the above expectation, Q-Learning often makes use of an Experience Replay (ER) buffer that stores the experiences of many state transitions.

In Actor-Critic (AC), both a policy (the actor) and an action-value function (the critic) are learned. The Critic is used to estimate the policy gradient (the direction of changes to the policy parameters that cause actions that generate higher expected returns), which is then used to update the policy function parameters at each training step.

### 2.3 MADDPG

The Markov Decision Process (MDP) framework regards other agents as part of the environment from the perspective of a single agent; so if other agents in the environment are learning and modifying their behaviour then the environment contains shifting dynamics (the environmental data-generating process is considered non-stationary). Deep Deterministic Policy Gradient (DDPG) is an actor-critic algorithm used in continuous control tasks. It was shown in () that the chance of sampling a policy-gradient update in an improved direction decreases exponentially with the number of agents being trained in the shared environment.

MADDPG is a modified actor-critic method designed to address the stability issues due to the simultaneous learning of policies in the multi-agent setting. A key component of MADDPG is the use of a shared critic that has access to the policies of all other agents during training. In MADDPG, agents can have different state and action spaces, and be governed by different reward functions. We use the MADDPG algorithm for all agents within our scenarios.

### 2.4 Agent design

When implementing an RL system there are many important design considerations:

- *Algorithm*: Different algorithms are suited to different tasks. A selected algorithm will need to perform well with the selected action-space, state-space, reward function and environmental dynamics.
- *State-space*: The state-space describes how environmental observations are presented to the algorithm. Constructing the correct, relevant abstractions inform how the agent ‘sees the world’.
- *Action-space*: The action-space describes actions available to the agent. The level of abstraction here should be fine enough for accurate control, but general enough for the policy to be learnable.
- *Reward function*: The reward function provides a scalar feedback value (positive or negative) to the agent. Most algorithms assume the reward signal contains no noise, and require point-estimates rather than a distribution, so crafting a consistent reward function that

reflects the precise desires of the designer can be challenging.

We examine the impact of design choices for state-space, action-space, and reward function in our scenarios.

### 3 Scenarios

#### 3.1 Zombie-Survival Game

The Zombie-Survival scenarios cover a set of games simulating survivors and zombies in a zombie-apocalypse scenario. Survivors attempt to distance themselves from zombies and are penalized (-10 reward) for each contact. Zombies attempt contact with survivors and are rewarded (+10 reward) for each contact. Zombies have the advantage of numbers (there are 5 zombies and 2 survivors), whereas survivors have the advantage of faster acceleration and a higher maximum speed. All reward functions are independent, there are no explicitly shared rewards for outcomes.

The game offers a scenario with asymmetric power dynamics between competitive teams, and allows the emergence of competitive or cooperative behavior within a team.

#### 3.2 Scenario: Baseline

We modify the 'Predator-prey' particle environment from (), which implements a multi-agent environment with a continuous action-space, a fully-observable state-space, and basic 2D physics. Each agent is represented as a circle that has mass, position, velocity, velocity dampening, maximum acceleration, and maximum speed. Actions are 4D discrete (softmax probabilities) which are mapped to 2D continuous force vectors to control movement. The predator-prey environment uses reward shaping to discourage agents from moving out of bounds. We replace the additional term in the reward function and implement fixed boundary walls. We run several training jobs for 10,000 steps each to capture the emergence of different policies.

#### 3.3 Scenario: Anonymity

#### 3.4 Scenario: Health

#### 3.5 Scenario: Armed

### 4 Discussion

FROM HERE FOLLOWS TEMPLATE STUFF

Type of Text	Font Size	Style
paper title	15 pt	bold
author names	12 pt	bold
author affiliation	12 pt	
the word "Abstract"	12 pt	bold
section titles	12 pt	bold
subsection titles	11 pt	bold
document text	11 pt	
captions	10 pt	
abstract text	10 pt	
bibliography	10 pt	
footnotes	9 pt	

Table 1: Font guide.

**L<sup>A</sup>T<sub>E</sub>X-specific details:** To use Times Roman in L<sup>A</sup>T<sub>E</sub>X2<sub>ε</sub>, put the following in the preamble:

```
\usepackage{times}
\usepackage{latexsym}
```

#### 4.1 Ruler

A printed ruler (line numbers in the left and right margins of the article) should be presented in the version submitted for review, so that reviewers may comment on particular lines in the paper without circumlocution. The presence or absence of the ruler should not change the appearance of any other content on the page. The camera ready copy should not contain a ruler.

**Reviewers:** note that the ruler measurements may not align well with lines in the paper – this turns out to be very difficult to do well when the paper contains many figures and equations, and, when done, looks ugly. In most cases one would expect that the approximate location will be adequate, although you can also use fractional references (*e.g.*, this line ends at mark 295.5).

**L<sup>A</sup>T<sub>E</sub>X-specific details:** The style files will generate the ruler when `\acelfinalcopy` is commented out, and remove it otherwise.

#### 4.2 Title and Authors

Center the title, author's name(s) and affiliation(s) across both columns. Do not use footnotes for affiliations. Place the title centered at the top of the first page, in a 15-point bold font. Long titles should be typed on two lines without a blank line intervening. Put the title 2.5 cm from the top of the page, followed by a blank line, then the author's names(s), and the affiliation on the following line. Do not

use only initials for given names (middle initials are allowed). Do not format surnames in all capitals (*e.g.*, use “Mitchell” not “MITCHELL”). Do not format title and section headings in all capitals except for proper names (such as “BLEU”) that are conventionally in all capitals. The affiliation should contain the author’s complete address, and if possible, an electronic mail address.

The title, author names and addresses should be completely identical to those entered to the electronic paper submission website in order to maintain the consistency of author information among all publications of the conference. If they are different, the publication chairs may resolve the difference without consulting with you; so it is in your own interest to double-check that the information is consistent.

Start the body of the first page 7.5 cm from the top of the page. **Even in the anonymous version of the paper, you should maintain space for names and addresses so that they will fit in the final (accepted) version.**

### 4.3 Abstract

Use two-column format when you begin the abstract. Type the abstract at the beginning of the first column. The width of the abstract text should be smaller than the width of the columns for the text in the body of the paper by 0.6 cm on each side. Center the word **Abstract** in a 12 point bold font above the body of the abstract. The abstract should be a concise summary of the general thesis and conclusions of the paper. It should be no longer than 200 words. The abstract text should be in 10 point font.

### 4.4 Text

Begin typing the main body of the text immediately after the abstract, observing the two-column format as shown in the present document.

Indent 0.4 cm when starting a new paragraph.

### 4.5 Sections

Format section and subsection headings in the style shown on the present document. Use numbered sections (Arabic numerals) to facilitate cross references. Number subsections with the section number and the subsection number separated by a dot, in Arabic numerals.

Command	Output	Command	Output
<code>{\ "a}</code>	ä	<code>{\ c c}</code>	ç
<code>{\ ^e}</code>	ê	<code>{\ u g}</code>	ğ
<code>{\ 'i}</code>	ì	<code>{\ l}</code>	ł
<code>{\ .I}</code>	İ	<code>{\ ~n}</code>	ñ
<code>{\ o}</code>	ø	<code>{\ H o}</code>	ő
<code>{\ 'u}</code>	ú	<code>{\ v r}</code>	ř
<code>{\ aa}</code>	å	<code>{\ ss}</code>	ß

Table 2: Example commands for accented characters, to be used in, *e.g.*, BIB<sub>T</sub>E<sub>X</sub> names.

### 4.6 Footnotes

Put footnotes at the bottom of the page and use 9 point font. They may be numbered or referred to by asterisks or other symbols.<sup>1</sup> Footnotes should be separated from the text by a line.<sup>2</sup>

### 4.7 Graphics

Place figures, tables, and photographs in the paper near where they are first discussed, rather than at the end, if possible. Wide illustrations may run across both columns. Color is allowed, but adhere to Section 4’s guidelines on accessibility.

**Captions:** Provide a caption for every illustration; number each one sequentially in the form: “Figure 1. Caption of the Figure.” “Table 1. Caption of the Table.” Type the captions of the figures and tables below the body, using 10 point text. Captions should be placed below illustrations. Captions that are one line are centered (see Table 1). Captions longer than one line are left-aligned (see Table 2).

**L<sub>A</sub>T<sub>E</sub>X-specific details:** The style files are compatible with the caption and subcaption packages; do not add optional arguments. **Do not override the default caption sizes.**

### 4.8 Hyperlinks

Within-document and external hyperlinks are indicated with Dark Blue text, Color Hex #000099.

### 4.9 Citations

Citations within the text appear in parentheses as (Gusfield, 1997) or, if the author’s name appears in the text itself, as Gusfield (1997). Append lowercase letters to the year in cases of ambiguities. Treat double authors as in (Aho and Ullman, 1972),

<sup>1</sup>This is how a footnote should appear.

<sup>2</sup>Note the line separating the footnotes from the text.

but write as in (Chandra et al., 1981) when more than two authors are involved. Collapse multiple citations as in (Gusfield, 1997; Aho and Ullman, 1972).

Refrain from using full citations as sentence constituents. Instead of

“(Gusfield, 1997) showed that ...”

write

“Gusfield (1997) showed that ...”

**L<sup>A</sup>T<sub>E</sub>X-specific details:** Table 3 shows the syntax supported by the style files. We encourage you to use the natbib styles. You can use the command `\citet` (cite in text) to get “author (year)” citations as in Gusfield (1997). You can use the command `\citep` (cite in parentheses) to get “(author, year)” citations as in (Gusfield, 1997). You can use the command `\citealp` (alternative cite without parentheses) to get “author year” citations (which is useful for using citations within parentheses, as in Gusfield, 1997).

#### 4.10 References

Gather the full set of references together under the heading **References**; place the section before any Appendices. Arrange the references alphabetically by first author, rather than by order of occurrence in the text.

Provide as complete a citation as possible, using a consistent format, such as the one for *Computational Linguistics* or the one in the *Publication Manual of the American Psychological Association* (American Psychological Association, 1983). Use full names for authors, not just initials.

Submissions should accurately reference prior and related work, including code and data. If a piece of prior work appeared in multiple venues, the version that appeared in a refereed, archival venue should be referenced. If multiple versions of a piece of prior work exist, the one used by the authors should be referenced. Authors should not rely on automated citation indices to provide accurate references for prior and related work.

The following text cites various types of articles so that the references section of the present document will include them.

- Example article in journal: (Ando and Zhang, 2005).

- Example article in proceedings, with location: (Börschinger and Johnson, 2011).

- Example article in proceedings, without location: (Andrew and Gao, 2007).

- Example arxiv paper: (Rasooli and Tetreault, 2015).

**L<sup>A</sup>T<sub>E</sub>X-specific details:** The L<sup>A</sup>T<sub>E</sub>X and BibT<sub>E</sub>X style files provided roughly follow the American Psychological Association format. If your own bib file is named `acl2020.bib`, then placing the following before any appendices in your L<sup>A</sup>T<sub>E</sub>X file will generate the references section for you:

```
\bibliographystyle{acl_natbib}
\bibliography{acl2020}
```

You can obtain the complete ACL Anthology as a BibT<sub>E</sub>X file from <https://aclweb.org/anthology/anthology.bib.gz>. To include both the anthology and your own bib file, use the following instead of the above.

```
\bibliographystyle{acl_natbib}
\bibliography{anthology,acl2020}
```

#### 4.11 Digital Object Identifiers

As part of our work to make ACL materials more widely used and cited outside of our discipline, ACL has registered as a CrossRef member, as a registrant of Digital Object Identifiers (DOIs), the standard for registering permanent URNs for referencing scholarly materials.

All camera-ready references are required to contain the appropriate DOIs (or as a second resort, the hyperlinked ACL Anthology Identifier) to all cited works. Appropriate records should be found for most materials in the current ACL Anthology at <http://aclanthology.info/>. As examples, we cite (Goodman et al., 2016) to show you how papers with a DOI will appear in the bibliography. We cite (Harper, 2014) to show how papers without a DOI but with an ACL Anthology Identifier will appear in the bibliography.

**L<sup>A</sup>T<sub>E</sub>X-specific details:** Please ensure that you use BibT<sub>E</sub>X records that contain DOI or URLs for any of the ACL materials that you reference. If the BibT<sub>E</sub>X file contains DOI fields, the paper title in the references section will appear as a hyperlink to the DOI, using the `hyperref` L<sup>A</sup>T<sub>E</sub>X package.

Output	natbib command	Old ACL-style command
(Gusfield, 1997)	<code>\citep</code>	<code>\cite</code>
Gusfield, 1997	<code>\citealp</code>	no equivalent
Gusfield (1997)	<code>\citet</code>	<code>\newcite</code>
(1997)	<code>\citeyearpar</code>	<code>\shortcite</code>

Table 3: Citation commands supported by the style file. The style is based on the natbib package and supports all natbib citation commands. It also supports commands defined in previous ACL style files for compatibility.

## 4.12 Appendices

Appendices, if any, directly follow the text and the references (but only in the camera-ready; see Appendix A). Letter them in sequence and provide an informative title: **Appendix A. Title of Appendix.**

## 5 Accessibility

In an effort to accommodate people who are color-blind (as well as those printing to paper), grayscale readability is strongly encouraged. Color is not forbidden, but authors should ensure that tables and figures do not rely solely on color to convey critical distinctions. A simple criterion: All curves and points in your figures should be clearly distinguishable without color.

## 6 Translation of non-English Terms

It is also advised to supplement non-English characters and terms with appropriate transliterations and/or translations since not all readers understand all such characters and terms. Inline transliteration or translation can be represented in the order of:

original-form  
transliteration  
“translation”

## 7 L<sup>A</sup>T<sub>E</sub>X Compilation Issues

You may encounter the following error during compilation:

```
\pdfendlink ended up in different nest-
ing level than \pdfstartlink.
```

This happens when `pdflatex` is used and a citation splits across a page boundary. To fix this, the style file contains a patch consisting of two lines: (1) `\RequirePackage{etoolbox}` (line 455 in `acl2020.sty`), and (2) A long line below (line 456 in `acl2020.sty`).

If you still encounter compilation issues even with the patch enabled, disable the patch by commenting the two lines, and then disable the

`hyperref` package by loading the style file with the `nohyperref` option:

```
\usepackage[nohyperref]{acl2020}
```

Then recompile, find the problematic citation, and rewrite the sentence containing the citation. (See, e.g., <http://tug.org/errors.html>)

## Acknowledgments

The acknowledgments should go immediately before the references. Do not number the acknowledgments section. Do not include this section when submitting your paper for review.

## References

- Alfred V. Aho and Jeffrey D. Ullman. 1972. *The Theory of Parsing, Translation and Compiling*, volume 1. Prentice-Hall, Englewood Cliffs, NJ.
- American Psychological Association. 1983. *Publications Manual*. American Psychological Association, Washington, DC.
- Rie Kubota Ando and Tong Zhang. 2005. A framework for learning predictive structures from multiple tasks and unlabeled data. *Journal of Machine Learning Research*, 6:1817–1853.
- Galen Andrew and Jianfeng Gao. 2007. Scalable training of L1-regularized log-linear models. In *Proceedings of the 24th International Conference on Machine Learning*, pages 33–40.
- Benjamin Börschinger and Mark Johnson. 2011. [A particle filter algorithm for Bayesian wordsegmentation](#). In *Proceedings of the Australasian Language Technology Association Workshop 2011*, pages 10–18, Canberra, Australia.
- Ashok K. Chandra, Dexter C. Kozen, and Larry J. Stockmeyer. 1981. [Alternation](#). *Journal of the Association for Computing Machinery*, 28(1):114–133.
- James Goodman, Andreas Vlachos, and Jason Naradowsky. 2016. [Noise reduction and targeted exploration in imitation learning for abstract meaning representation parsing](#). In *Proceedings of the 54th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, pages 1–11, Berlin, Germany. Association for Computational Linguistics.



Dan Gusfield. 1997. *Algorithms on Strings, Trees and Sequences*. Cambridge University Press, Cambridge, UK.

Mary Harper. 2014. [Learning from 26 languages: Program management and science in the babel program](#). In *Proceedings of COLING 2014, the 25th International Conference on Computational Linguistics: Technical Papers*, page 1, Dublin, Ireland. Dublin City University and Association for Computational Linguistics.

Mohammad Sadegh Rasooli and Joel R. Tetreault. 2015. [Yara parser: A fast and accurate dependency parser](#). *Computing Research Repository*, arXiv:1503.06733. Version 2.

The paper should not rely on the supplementary material: while the paper may refer to and cite the supplementary material and the supplementary material will be available to the reviewers, they will not be asked to review the supplementary material.

## A Appendices

Appendices are material that can be read, and include lemmas, formulas, proofs, and tables that are not critical to the reading and understanding of the paper. Appendices should be **uploaded as supplementary material** when submitting the paper for review. Upon acceptance, the appendices come after the references, as shown here.

**L<sup>A</sup>T<sub>E</sub>X-specific details:** Use `\appendix` before any appendix section to switch the section numbering over to letters.

## B Supplemental Material

Submissions may include non-readable supplementary material used in the work and described in the paper. Any accompanying software and/or data should include licenses and documentation of research review as appropriate. Supplementary material may report preprocessing decisions, model parameters, and other details necessary for the replication of the experiments reported in the paper. Seemingly small preprocessing decisions can sometimes make a large difference in performance, so it is crucial to record such decisions to precisely characterize state-of-the-art methods.

Nonetheless, supplementary material should be supplementary (rather than central) to the paper. **Submissions that misuse the supplementary material may be rejected without review.** Supplementary material may include explanations or details of proofs or derivations that do not fit into the paper, lists of features or feature templates, sample inputs and outputs for a system, pseudo-code or source code, and data. (Source code and data should be separate uploads, rather than part of the paper).