

Reinforcement learning resources curated <http://aikorea.org/awesome-rl> **111** commits **2** branches **0** releases **27** contributorsBranch: **master** ▾[New pull request](#)[Create new file](#)[Upload files](#)[Find file](#)[Clone or download ▾](#) **hshyunsookim** committed on **GitHub** Merge pull request [#36](#) from costashatz/master ... Latest commit e7ed6e6 on 28 Aug [README.md](#)

Added ITE and Black-DROPS papers/codes + minor typo

a month ago

 [README.md](#)

Awesome Reinforcement Learning

A curated list of resources dedicated to reinforcement learning.

We have pages for other topics: [awesome-rnn](#), [awesome-deep-vision](#), [awesome-random-forest](#)

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We are looking for more contributors and maintainers!

Contributing

Please feel free to [pull requests](#)

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Codes

- Codes for examples and exercises in Richard Sutton and Andrew Barto's Reinforcement Learning: An Introduction
- [Python Code](#)
- [MATLAB Code](#)
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- Simulation code for Reinforcement Learning Control Problems

- [Pole-Cart Problem](#)
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- [MATLAB Environment and GUI for Reinforcement Learning](#)
- [Reinforcement Learning Repository - University of Massachusetts, Amherst](#)
- [Brown-UMBC Reinforcement Learning and Planning Library \(Java\)](#)
- [Reinforcement Learning in R \(MDP, Value Iteration\)](#)
- [Reinforcement Learning Environment in Python and MATLAB](#)
- [RL-Glue](#) (standard interface for RL) and [RL-Glue Library](#)
- [PyBrain Library](#) - Python-Based Reinforcement learning, Artificial intelligence, and Neural network
- [RLPy Framework](#) - Value-Function-Based Reinforcement Learning Framework for Education and Research
- [Maja](#) - Machine learning framework for problems in Reinforcement Learning in python
- [TeachingBox](#) - Java based Reinforcement Learning framework
- [Policy Gradient Reinforcement Learning Toolbox for MATLAB](#)
- [PIQLE](#) - Platform Implementing Q-Learning and other RL algorithms
- [BeliefBox](#) - Bayesian reinforcement learning library and toolkit
- [Deep Q-Learning with Tensor Flow](#) - A deep Q learning demonstration using Google Tensorflow
- [Atari](#) - Deep Q-networks and asynchronous agents in Torch
- [AgentNet](#) - A python library for deep reinforcement learning and custom recurrent networks using Theano+Lasagne.
- [Reinforcement Learning Examples by RLCode](#) - A Collection of minimal and clean reinforcement learning examples
- [PyTorch Deep RL](#) - Popular deep RL algorithm implementations with PyTorch
- [Black-DROPS](#) - Modular and generic code for the model-based policy search Black-DROPS algorithm (IROS 2017 paper) and easy integration with the [DART](#) simulator

Theory

Lectures

- [UCL] [COMPM050/COMPGI13 Reinforcement Learning](#) by David Silver
- [UC Berkeley] CS188 Artificial Intelligence by Pieter Abbeel
 - [Lecture 8: Markov Decision Processes 1](#)
 - [Lecture 9: Markov Decision Processes 2](#)
 - [Lecture 10: Reinforcement Learning 1](#)
 - [Lecture 11: Reinforcement Learning 2](#)
- [Udacity (Georgia Tech.)] [CS7642 Reinforcement Learning](#)
- [Stanford] [CS229 Machine Learning - Lecture 16: Reinforcement Learning](#) by Andrew Ng
- [UC Berkeley] [CS294 Deep Reinforcement Learning](#) by John Schulman and Pieter Abbeel
- [CMU] [10703: Deep Reinforcement Learning and Control, Spring 2017](#)
- [MIT] [6.S094: Deep Learning for Self-Driving Cars](#)
 - [Lecture 2: Deep Reinforcement Learning for Motion Planning](#)

Books

- Richard Sutton and Andrew Barto, Reinforcement Learning: An Introduction [\[Book\]](#) [\[Code\]](#)
- Csaba Szepesvari, Algorithms for Reinforcement Learning [\[Book\]](#)
- David Poole and Alan Mackworth, Artificial Intelligence: Foundations of Computational Agents [\[Book Chapter\]](#)
- Dimitri P. Bertsekas and John N. Tsitsiklis, Neuro-Dynamic Programming [\[Book \(Amazon\)\]](#) [\[Summary\]](#)
- Mykel J. Kochenderfer, Decision Making Under Uncertainty: Theory and Application [\[Book \(Amazon\)\]](#)

Surveys

- Leslie Pack Kaelbling, Michael L. Littman, Andrew W. Moore, Reinforcement Learning: A Survey, JAIR, 1996. [\[Paper\]](#)
- S. S. Keerthi and B. Ravindran, A Tutorial Survey of Reinforcement Learning, Sadhana, 1994. [\[Paper\]](#)
- Matthew E. Taylor, Peter Stone, Transfer Learning for Reinforcement Learning Domains: A Survey, JMLR, 2009. [\[Paper\]](#)

- Jens Kober, J. Andrew Bagnell, Jan Peters, Reinforcement Learning in Robotics, A Survey, IJRR, 2013. [\[Paper\]](#)
- Michael L. Littman, "Reinforcement learning improves behaviour from evaluative feedback." Nature 521.7553 (2015): 445-451. [\[Paper\]](#)
- Marc P. Deisenroth, Gerhard Neumann, Jan Peter, A Survey on Policy Search for Robotics, Foundations and Trends in Robotics, 2014. [\[Book\]](#)

Papers / Thesis

Foundational Papers

- Marvin Minsky, Steps toward Artificial Intelligence, Proceedings of the IRE, 1961. [\[Paper\]](#) (discusses issues in RL such as the "credit assignment problem")
- Ian H. Witten, An Adaptive Optimal Controller for Discrete-Time Markov Environments, Information and Control, 1977. [\[Paper\]](#) (earliest publication on temporal-difference (TD) learning rule)

Methods

- Dynamic Programming (DP):
 - Christopher J. C. H. Watkins, Learning from Delayed Rewards, Ph.D. Thesis, Cambridge University, 1989. [\[Thesis\]](#)
- Monte Carlo:
 - Andrew Barto, Michael Duff, Monte Carlo Inversion and Reinforcement Learning, NIPS, 1994. [\[Paper\]](#)
 - Satinder P. Singh, Richard S. Sutton, Reinforcement Learning with Replacing Eligibility Traces, Machine Learning, 1996. [\[Paper\]](#)
- Temporal-Difference:
 - Richard S. Sutton, Learning to predict by the methods of temporal differences. Machine Learning 3: 9-44, 1988. [\[Paper\]](#)
- Q-Learning (Off-policy TD algorithm):
 - Chris Watkins, Learning from Delayed Rewards, Cambridge, 1989. [\[Thesis\]](#)
- Sarsa (On-policy TD algorithm):

- G.A. Rummery, M. Niranjan, On-line Q-learning using connectionist systems, Technical Report, Cambridge Univ., 1994. [\[Report\]](#)
- Richard S. Sutton, Generalization in Reinforcement Learning: Successful examples using sparse coding, NIPS, 1996. [\[Paper\]](#)
- R-Learning (learning of relative values)
 - Andrew Schwartz, A Reinforcement Learning Method for Maximizing Undiscounted Rewards, ICML, 1993. [\[Paper-Google Scholar\]](#)
- Function Approximation methods (Least-Square Temporal Difference, Least-Square Policy Iteration)
 - Steven J. Bradtke, Andrew G. Barto, Linear Least-Squares Algorithms for Temporal Difference Learning, Machine Learning, 1996. [\[Paper\]](#)
 - Michail G. Lagoudakis, Ronald Parr, Model-Free Least Squares Policy Iteration, NIPS, 2001. [\[Paper\]](#) [\[Code\]](#)
- Policy Search / Policy Gradient
 - Richard Sutton, David McAllester, Satinder Singh, Yishay Mansour, Policy Gradient Methods for Reinforcement Learning with Function Approximation, NIPS, 1999. [\[Paper\]](#)
 - Jan Peters, Sethu Vijayakumar, Stefan Schaal, Natural Actor-Critic, ECML, 2005. [\[Paper\]](#)
 - Jens Kober, Jan Peters, Policy Search for Motor Primitives in Robotics, NIPS, 2009. [\[Paper\]](#)
 - Jan Peters, Katharina Mulling, Yasemin Altun, Relative Entropy Policy Search, AAAI, 2010. [\[Paper\]](#)
 - Freek Stulp, Olivier Sigaud, Path Integral Policy Improvement with Covariance Matrix Adaptation, ICML, 2012. [\[Paper\]](#)
 - Nate Kohl, Peter Stone, Policy Gradient Reinforcement Learning for Fast Quadrupedal Locomotion, ICRA, 2004. [\[Paper\]](#)
 - Marc Deisenroth, Carl Rasmussen, PILCO: A Model-Based and Data-Efficient Approach to Policy Search, ICML, 2011. [\[Paper\]](#)
 - Scott Kuindersma, Roderic Grupen, Andrew Barto, Learning Dynamic Arm Motions for Postural Recovery, Humanoids, 2011. [\[Paper\]](#)
 - Konstantinos Chatzilygeroudis, Roberto Rama, Rituraj Kaushik, Dorian Goepp, Vassilis Vassiliades, Jean-Baptiste Mouret, Black-Box Data-efficient Policy Search for Robotics, IROS, 2017. [\[Paper\]](#)

- Hierarchical RL
 - Richard Sutton, Doina Precup, Satinder Singh, Between MDPs and Semi-MDPs: A Framework for Temporal Abstraction in Reinforcement Learning, Artificial Intelligence, 1999. [\[Paper\]](#)
 - George Konidaris, Andrew Barto, Building Portable Options: Skill Transfer in Reinforcement Learning, IJCAI, 2007. [\[Paper\]](#)
- Deep Learning + Reinforcement Learning (A sample of recent works on DL+RL)
 - V. Mnih, et. al., Human-level Control through Deep Reinforcement Learning, Nature, 2015. [\[Paper\]](#)
 - Xiaoxiao Guo, Satinder Singh, Honglak Lee, Richard Lewis, Xiaoshi Wang, Deep Learning for Real-Time Atari Game Play Using Offline Monte-Carlo Tree Search Planning, NIPS, 2014. [\[Paper\]](#)
 - Sergey Levine, Chelsea Finn, Trevor Darrel, Pieter Abbeel, End-to-End Training of Deep Visuomotor Policies. ArXiv, 16 Oct 2015. [\[ArXiv\]](#)
 - Tom Schaul, John Quan, Ioannis Antonoglou, David Silver, Prioritized Experience Replay, ArXiv, 18 Nov 2015. [\[ArXiv\]](#)
 - Hado van Hasselt, Arthur Guez, David Silver, Deep Reinforcement Learning with Double Q-Learning, ArXiv, 22 Sep 2015. [\[ArXiv\]](#)
 - Volodymyr Mnih, Adrià Puigdomènech Badia, Mehdi Mirza, Alex Graves, Timothy P. Lillicrap, Tim Harley, David Silver, Koray Kavukcuoglu, Asynchronous Methods for Deep Reinforcement Learning, ArXiv, 4 Feb 2016. [\[ArXiv\]](#)

Applications

Game Playing

Traditional Games

- Backgammon - "TD-Gammon" game play using TD(λ) (Tesauro, ACM 1995) [\[Paper\]](#)
- Chess - "KnightCap" program using TD(λ) (Baxter, arXiv 1999) [\[arXiv\]](#)
- Chess - Giraffe: Using deep reinforcement learning to play chess (Lai, arXiv 2015) [\[arXiv\]](#)

Computer Games

- Human-level Control through Deep Reinforcement Learning (Mnih, Nature 2015) [\[Paper\]](#) [\[Code\]](#) [\[Video\]](#)
- [Flappy Bird Reinforcement Learning](#) [\[Video\]](#)
- Marl/O - learning to play Mario with evolutionary reinforcement learning using artificial neural networks (Stanley, Evolutionary Computation 2002) [\[Paper\]](#) [\[Video\]](#)

Robotics

- Policy Gradient Reinforcement Learning for Fast Quadrupedal Locomotion (Kohl, ICRA 2004) [\[Paper\]](#)
- Robot Motor Skill Coordination with EM-based Reinforcement Learning (Kormushev, IROS 2010) [\[Paper\]](#) [\[Video\]](#)
- Generalized Model Learning for Reinforcement Learning on a Humanoid Robot (Hester, ICRA 2010) [\[Paper\]](#) [\[Video\]](#)
- Autonomous Skill Acquisition on a Mobile Manipulator (Konidaris, AAAI 2011) [\[Paper\]](#) [\[Video\]](#)
- PILCO: A Model-Based and Data-Efficient Approach to Policy Search (Deisenroth, ICML 2011) [\[Paper\]](#)
- Incremental Semantically Grounded Learning from Demonstration (Niekum, RSS 2013) [\[Paper\]](#)
- Efficient Reinforcement Learning for Robots using Informative Simulated Priors (Cutler, ICRA 2015) [\[Paper\]](#) [\[Video\]](#)
- Robots that can adapt like animals (Cully, Nature 2015) [\[Paper\]](#) [\[Video\]](#) [\[Code\]](#)
- Black-Box Data-efficient Policy Search for Robotics (Chatzilygeroudis, IROS 2017) [\[Paper\]](#) [\[Video\]](#) [\[Code\]](#)

Control

- An Application of Reinforcement Learning to Aerobatic Helicopter Flight (Abbeel, NIPS 2006) [\[Paper\]](#) [\[Video\]](#)
- Autonomous helicopter control using Reinforcement Learning Policy Search Methods (Bagnell, ICRA 2011) [\[Paper\]](#)

Operations Research

- Scaling Average-reward Reinforcement Learning for Product Delivery (Proper, AAAI 2004) [\[Paper\]](#)
- Cross Channel Optimized Marketing by Reinforcement Learning (Abe, KDD 2004) [\[Paper\]](#)

Human Computer Interaction

- Optimizing Dialogue Management with Reinforcement Learning: Experiments with the NJFun System (Singh, JAIR 2002) [\[Paper\]](#)

Tutorials / Websites

- Mance Harmon and Stephanie Harmon, [Reinforcement Learning: A Tutorial](#)
- C. Igel, M.A. Riedmiller, et al., Reinforcement Learning in a Nutshell, ESANN, 2007. [\[Paper\]](#)
- UNSW - [Reinforcement Learning](#)
- [Introduction](#)
- [TD-Learning](#)
- [Q-Learning and SARSA](#)
- [Applet for "Cat and Mouse" Game](#)
- [ROS Reinforcement Learning Tutorial](#)
- [POMDP for Dummies](#)
- Scholarpedia articles on:
 - [Reinforcement Learning](#)
 - [Temporal Difference Learning](#)
- Repository with useful [MATLAB Software, presentations, and demo videos](#)
- [Bibliography on Reinforcement Learning](#)
- UC Berkeley - CS 294: Deep Reinforcement Learning, Fall 2015 (John Schulman, Pieter Abbeel) [\[Class Website\]](#)
- [Blog posts on Reinforcement Learning, Parts 1-4](#) by Travis DeWolf
- [The Arcade Learning Environment](#) - Atari 2600 games environment for developing AI agents
- [Deep Reinforcement Learning: Pong from Pixels](#) by Andrej Karpathy
- [Demystifying Deep Reinforcement Learning](#)

- [Let's make a DQN](#)
- [Simple Reinforcement Learning with Tensorflow, Parts 0-8](#) by Arthur Juliani
- [Practical_RL](#) - github-based course in reinforcement learning in the wild (lectures, coding labs, projects)

Online Demos

- [Real-world demonstrations of Reinforcement Learning](#)
- [Deep Q-Learning Demo](#) - A deep Q learning demonstration using ConvNetJS
- [Deep Q-Learning with Tensor Flow](#) - A deep Q learning demonstration using Google Tensorflow
- [Reinforcement Learning Demo](#) - A reinforcement learning demo using reinforcejs by Andrej Karpathy

Open Source Reinforcement Learning Platforms

- [OpenAI gym](#) - A toolkit for developing and comparing reinforcement learning algorithms
- [OpenAI universe](#) - A software platform for measuring and training an AI's general intelligence across the world's supply of games, websites and other applications
- [DeepMind Lab](#) - A customisable 3D platform for agent-based AI research
- [Project Malmo](#) - A platform for Artificial Intelligence experimentation and research built on top of Minecraft by Microsoft
- [ViZDoom](#) - Doom-based AI research platform for reinforcement learning from raw visual information
- [Retro Learning Environment](#) - An AI platform for reinforcement learning based on video game emulators. Currently supports SNES and Sega Genesis. Compatible with OpenAI gym.
- [torch-twrl](#) - A package that enables reinforcement learning in Torch by Twitter
- [UETorch](#) - A Torch plugin for Unreal Engine 4 by Facebook
- [TorchCraft](#) - Connecting Torch to StarCraft
- [rlab](#) - A framework for developing and evaluating reinforcement learning algorithms, fully compatible with OpenAI Gym

- [TensorForce](#) - Practical deep reinforcement learning on TensorFlow with Gitter support and OpenAI Gym/Universe/DeepMind Lab integration.
- [OpenAI lab](#) - An experimentation system for Reinforcement Learning using OpenAI Gym, Tensorflow, and Keras.
- [keras-rl](#) - State-of-the art deep reinforcement learning algorithms in Keras designed for compatibility with OpenAI.
- [BURLAP](#) - Brown-UMBC Reinforcement Learning and Planning, a library written in Java