

CS50's Introduction to Artificial Intelligence with Python

OpenCourseWare

Donate [\(https://cs50.harvard.edu/donate/\)](https://cs50.harvard.edu/donate/)

Brian Yu <https://brianyu.me>
brian@cs.harvard.edu

David J. Malan <https://cs.harvard.edu/malan/>
malan@harvard.edu

[f \(https://www.facebook.com/dmalan/\)](https://www.facebook.com/dmalan/) [🐙 \(https://github.com/dmalan/\)](https://github.com/dmalan/) [@ \(https://www.instagram.com/davidjmalan/\)](https://www.instagram.com/davidjmalan/) [in \(https://www.linkedin.com/in/malan/\)](https://www.linkedin.com/in/malan/) [🗯 \(https://www.reddit.com/user/davidjmalan\)](https://www.reddit.com/user/davidjmalan/) [@ \(https://www.threads.net/@davidjmalan\)](https://www.threads.net/@davidjmalan) [🐦 \(https://twitter.com/davidjmalan\)](https://twitter.com/davidjmalan)

Nim

The latest version of Python you should use in this course is Python 3.12.

Write an AI that teaches itself to play Nim through reinforcement learning.

```
$ python play.py
Playing training game 1
Playing training game 2
Playing training game 3
...
Playing training game 9999
Playing training game 10000
Done training

Piles:
Pile 0: 1
Pile 1: 3
Pile 2: 5
Pile 3: 7

AI's Turn
AI chose to take 1 from pile 2.
```

When to Do It

By Wednesday, January 1, 2025 at 1:59 AM GMT-3 (<https://time.cs50.io/20241231T235900-0500>)

How to Get Help

- 1. Ask questions via [Ed \(https://cs50.edx.org/ed/\)](https://cs50.edx.org/ed/)
- 2. Ask questions via any of CS50's [communities!](#)

Background

Recall that in the game Nim, we begin with some number of piles, each with some number of objects. Players take turns: on a player's turn, the player removes any non-negative number of objects from any one non-empty pile. Whoever removes the last object loses.

There's some simple strategy you might imagine for this game: if there's only one pile and three objects left in it, and it's your turn, your best bet is to remove two of those objects, leaving your opponent with the third and final object to remove. But if there are more piles, the strategy gets considerably more complicated. In this problem, we'll build an AI to learn the strategy for this game through reinforcement learning. By playing against itself repeatedly and learning from experience, eventually our AI will learn which actions to take and which actions to avoid.

In particular, we'll use Q-learning for this project. Recall that in Q-learning, we try to learn a reward value (a number) for every (state, action) pair. An action that loses the game will have a reward of -1, an action that results in the other player losing the game will have a reward of 1, and an action that results in the game continuing has an immediate reward of 0, but will also have some future reward.

How will we represent the states and actions inside of a Python program? A "state" of the Nim game is just the current size of all of the piles. A state, for example, might be [1, 1, 3, 5], representing the state with 1 object in pile 0, 1 object in pile 1, 3 objects in pile 2, and 5 objects in pile 3. An "action" in the Nim game will be a pair of integers (i, j), representing the action of taking j objects from pile i. So the action (3, 5) represents the action "from pile 3, take away 5 objects." Applying that action to the state [1, 1, 3, 5] would result in the new state [1, 1, 3, 0] (the same state, but with pile 3 now empty).

Recall that the key formula for Q-learning is below. Everytime we are in a state s and take an action a, we can update the Q-value Q(s, a) according to:

```
Q(s, a) <- Q(s, a) + alpha * (new value estimate - old value estimate)
```

In the above formula, alpha is the learning rate (how much we value new information compared to information we already have). The new value estimate represents the sum of the reward received for the current action and the estimate of all the future rewards that the player will receive. The old value estimate is just the existing value for Q(s, a). By applying this formula everytime our AI takes a new action, over time our AI will start to learn which actions are better in any state.

Getting Started

- Download the distribution code from <https://cdn.cs50.net/ai/2023/x/projects/4/nim.zip> (<https://cdn.cs50.net/ai/2023/x/projects/4/nim.zip>) and unzip it.

Understanding

First, open up nim.py. There are two classes defined in this file (Nim and NimAI) along with two functions (train and play). Nim, train, and play have already been implemented for you, while NimAI leaves a few functions left for you to implement.

Take a look at the Nim class, which defines how a Nim game is played. In the __init__ function, notice that every Nim game needs to keep track of a list of piles, a current player (0 or 1), and the winner of the game (if one exists). The available_actions function returns a set of all the available actions in a state. For example, Nim.available_actions([2, 1, 0, 0]) returns the set {(0, 1), (1, 1), (0, 2)}, since the three possible actions are to take either 1 or 2 objects from pile 0, or to take 1 object from pile 1.

The remaining functions are used to define the gameplay: the other_player function determines who the opponent of a given player is, switch_player changes the current player to the opposing player, and move performs an action on the current state and switches the current player to the opposing player.

Next, take a look at the NimAI class, which defines our AI that will learn to play Nim. Notice that in the __init__ function, we start with an empty self.q dictionary. The self.q dictionary will keep track of all of the current Q-values learned by our AI by mapping (state, action) pairs to a numerical value. As an implementation detail, though we usually represent state as a list, since lists can't be used as Python dictionary keys, we'll instead use a tuple version of the state when getting or setting values in self.q.

For example, if we wanted to set the Q-value of the state [0, 0, 0, 2] and the action (3, 2) to -1, we would write something like

```
self.q[(0, 0, 0, 2), (3, 2)] = -1
```

Notice, too, that every NimAI object has an alpha and epsilon value that will be used for Q-learning and for action selection, respectively.

The update function is written for you, and takes as input state old_state, an action take in that state action, the resulting state after performing that action new_state, and an immediate reward for taking that action reward. The function then performs Q-learning by first getting the current Q-value for the state and action (by calling get_q_value), determining the best possible future rewards (by calling best_future_reward), and then using both of those values to update the Q-value (by calling update_q_value). Those three functions are left to you to implement.

Finally, the last function left unimplemented is the choose_action function, which selects an action to take in a given state (either greedily, or using the epsilon-greedy algorithm).

The Nim and NimAI classes are ultimately used in the train and play functions. The train function trains an AI by running n simulated games against itself, returning the fully trained AI. The play function accepts a trained AI as input, and lets a human player play a game of Nim against the AI.

Specification

Complete the implementation of get_q_value, update_q_value, best_future_reward, and choose_action in nim.py. For each of these functions, anytime a function accepts a state as input, you may assume it is a list of integers. Anytime a function accepts an action as input, you may assume it is an integer pair (i, j) of a pile i and a number of objects j.

The get_q_value function should accept as input a state and action and return the corresponding Q-value for that state/action pair.

- Recall that Q-values are stored in the dictionary self.q. The keys of self.q should be in the form of (state, action) pairs, where state is a tuple of all piles sizes in order, and action is a tuple (i, j) representing a pile and a number.
- If no Q-value for the state/action pair exists in self.q, then the function should return 0.

The update_q_value function takes a state state, an action action, an existing Q-value old_q, a current reward reward, and an estimate of future rewards future_rewards, and updates the Q-value for the state/action pair according to the Q-learning formula.

- Recall that the Q-learning formula is: Q(s, a) <- old value estimate + alpha * (new value estimate - old value estimate)
- Recall that alpha is the learning rate associated with the NimAI object.
- The old value estimate is just the existing Q-value for the state/action pair. The new value estimate should be the sum of the current reward and the estimated future reward.

The best_future_reward function accepts a state as input and returns the best possible reward for any available action in that state, according to the data in self.q.

- For any action that doesn't already exist in self.q for the given state, you should assume it has a Q-value of 0.
- If no actions are available in the state, you should return 0.

The choose_action function should accept a state as input (and optionally an epsilon flag for whether to use the epsilon-greedy algorithm), and return an available action in that state.

- If epsilon is False, your function should behave greedily and return the best possible action available in that state (i.e., the action that has the highest Q-value, using 0 if no Q-value is known).
- If epsilon is True, your function should behave according to the epsilon-greedy algorithm, choosing a random available action with probability self.epsilon and otherwise choosing the best action available.
- If multiple actions have the same Q-value, any of those options is an acceptable return value.

You should not modify anything else in nim.py other than the functions the specification calls for you to implement, though you may write additional functions and/or import other Python standard library modules. You may also import numpy or pandas, if familiar with them, but you should not use any other third-party Python modules. You may modify play.py to test on your own.

Hints

- If lst is a list, then tuple(lst) can be used to convert lst into a tuple.

Testing

If you'd like, you can execute the below (after setting up check50 (<https://cs50.readthedocs.io/projects/check50/en/latest/index.html>) on your system) to evaluate the correctness of your code. This isn't obligatory; you can simply submit following the steps at the end of this specification, and these same tests will run on our server. Either way, be sure to compile and test it yourself as well!

```
check50 a150/projects/2024/x/nim
```

Execute the below to evaluate the style of your code using style50.

```
style50 nim.py
```

Remember that you **may not import any modules** (other than those in the Python standard library) **other than those explicitly authorized herein**. Doing so will not only prevent check50 from running, but will also prevent submit50 from scoring your assignment, since it uses check50. If that happens, you've likely imported something disallowed or otherwise modified the distribution code in an unauthorized manner, per the specification. There are certainly tools out there that trivialize some of these projects, but that's not the goal here; you're learning things at a lower level. If we don't say here that you can use them, you can't use them.

How to Submit

Beginning **Monday, January 1, 2024 at 2:00 AM GMT-3** (<https://time.cs50.io/20240101T000000-0500>), the course has transitioned to a new submission platform. If you had not completed CS50 AI prior to that time, **you must join the new course pursuant to Step 1, below**, and also must resubmit all of your past projects using the new submission slugs to import their scores. We apologize for the inconvenience, but hope you feel that access to check50, which is new for 2024, is a worthwhile trade-off for it, [here!](#)

- Visit [this link \(https://submit.cs50.io/\)](https://submit.cs50.io/) (writes/d03c31aef1984c29b5e7b268c5a87b7b), log in with your GitHub account, and click **Authorize cs50**. Then, check the box indicating that you'd like to grant course staff access to your submissions, and click **Join course**.
- Install Git** (<https://git-scm.com/downloads>) and, optionally, **install submit50** (<https://cs50.readthedocs.io/submit50/>).
- If you've installed submit50, execute

```
submit50 a150/projects/2024/x/nim
```

If you submit your code directly using Git, rather than `submit50`, **do not** include files or folders other than those you are actually instructed to modify in the specification above. (That is to say, don't upload your entire directory!)

Work should be graded within five minutes. You can then go to <https://cs50.me/cs50ai> (<https://cs50.me/cs50ai>) to view your current progress!