

# Project 3: Multi-Agent Search

Deadline: 11:59pm, Jun.29, 2023

## Abstract

The goal of this project is to help you better understand multi-agent search problems and adversarial search algorithms.

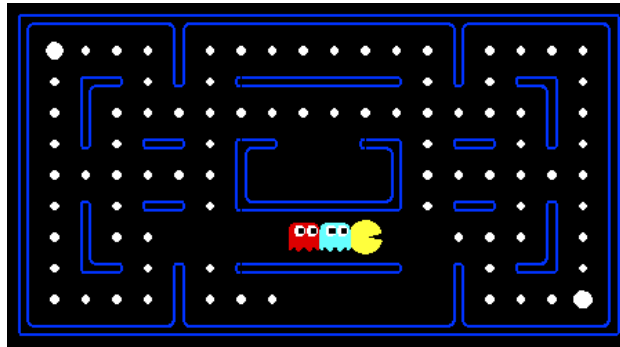


Figure 1: Pacman, now with ghosts. Minimax, Expectimax, Evaluation.

## Introduction

In this project, you will design agents for the classic version of Pacman, including ghosts. Along the way, you will implement both minimax and expectimax search and try your hand at evaluation function design.

The code base has not changed much from the previous project, but please start with a **fresh installation**, rather than intermingling files from project 1.

The code for this project consists of several Python files, some of which you will need to read and understand in order to complete the assignment, and some of which you can ignore. You can download all the code and supporting files in the folder Projects on Canvas.

<b>Files you'll edit:</b>	
<code>multiAgents.py</code>	Where all of your multi-agent search agents will reside.
<b>Files you might want to look at:</b>	
<code>pacman.py</code>	The main file that runs Pacman games. This file describes a Pacman GameState type, which you use in this project.
<code>game.py</code>	The logic behind how the Pacman world works. This file describes several supporting types like AgentState, Agent, Direction, and Grid.
<code>util.py</code>	Useful data structures for implementing search algorithms.
<b>Supporting files you can ignore:</b>	
<code>graphicsDisplay.py</code>	Graphics for Pacman
<code>graphicsUtils.py</code>	Support for Pacman graphics
<code>textDisplay.py</code>	ASCII graphics for Pacman
<code>ghostAgents.py</code>	Agents to control ghosts
<code>keyboardAgents.py</code>	Keyboard interfaces to control Pacman
<code>layout.py</code>	Code for reading layout files and storing their contents

**Files to Edit and Submit:** You will fill in portions of `multiAgents.py` during the assignment. Please *do not* change the other files in this distribution or submit any of our original files other than these files.

**Evaluation:** Your code will be autograded for technical correctness. Please *do not* change the names of any provided functions or classes within the code, or you will wreak havoc on the autograder. However, the correctness of your implementation – not the online judge's judgements – will be the final judge of your score. If necessary, we will review and grade assignments individually to ensure that you receive due credit for your work.

**Academic Dishonesty:** We will be checking your code against other submissions in the class, but also codes found on internet, for logical redundancy. If you copy someone else's code and submit it with minor changes, we will know. These cheat detectors are quite hard to fool, so please don't try. We trust you all to submit your own work only; please don't let us down. If you do, we will pursue the strongest consequences available to us.

**Getting Help:** You are not alone! If you find yourself stuck on something, contact the course staff for help. Office hours and the discussion forum on Piazza are there for your support; please use them. If you can't make our office hours, let us know and we will schedule more. We want these projects to be rewarding and instructional, not frustrating and demoralizing. But, we don't know when or how to help unless you ask.

**Discussion:** Please be careful not to post spoilers.

## Welcome to Multi-Agent Pacman

After downloading the code, unzipping it, and changing to the directory, you should be able to play a game of Pacman by typing the following at the command line:

```
python pacman.py
```

and using the arrow keys to move. Now, run the provided `ReflexAgent` in `multiAgents.py`

```
python pacman.py -p ReflexAgent
```

Note that it plays quite poorly even on simple layouts:

```
python pacman.py -p ReflexAgent -l testClassic
```

Inspect its code (in `multiAgents.py`) and make sure you understand what it's doing.

## Question 1 (4 points): Reflex Agent

Improve the `ReflexAgent` in `multiAgents.py` to play respectably. The provided reflex agent code provides some helpful examples of methods that query the `GameState` for information. **A capable reflex agent will have to consider both food locations and ghost locations to perform well.** Your agent should easily and reliably clear the `testClassic` layout:

```
python pacman.py -p ReflexAgent -l testClassic
```

Try out your reflex agent on the default `mediumClassic` layout with one ghost or two (and animation off to speed up the display):

```
python pacman.py --frameTime 0 -p ReflexAgent -k 1  
python pacman.py --frameTime 0 -p ReflexAgent -k 2
```

How does your agent fare? It will likely often die with 2 ghosts on the default board, unless your evaluation function is quite good.

*Note:* Remember that `newFood` has the function `asList()`

*Note:* As features, try the reciprocal of important values (such as distance to food) rather than just the values themselves.

*Note:* The evaluation function you're writing is evaluating state-action pairs; in later parts of the project, you'll be evaluating states.

*Note:* You may find it useful to view the internal contents of various objects for debugging. You can do this by printing the objects' string representations.

For example, you can print `newGhostStates` with `print(newGhostStates)`.

*Options:* Default ghosts are random; you can also play for fun with slightly smarter directional ghosts using `-g DirectionalGhost`. If the randomness is preventing you from telling whether your agent is improving, you can use `-f` to run with a fixed random seed (same random choices every game). You can also play multiple games in a row with `-n`. Turn off graphics with `-q` to run lots of games quickly.

*Grading:* We will run your agent on the openClassic layout 10 times. You will receive full points if your agent's average score is greater than 1000.

Don't spend too much time on this question, though, as the meat of the project lies ahead.

## Question 2 (5 points): Minimax

Now you will write an adversarial search agent in the provided `MinimaxAgent` class stub in `multiAgents.py`. Your minimax agent should work with any number of ghosts, so you'll have to write an algorithm that is slightly more general than what you've previously seen in lecture. In particular, your minimax tree will have multiple min layers (one for each ghost) for every max layer.

Your code should also expand the game tree to an arbitrary depth. Score the leaves of your minimax tree with the supplied `self.evaluationFunction`, which defaults to `scoreEvaluationFunction`. `MinimaxAgent` extends `MultiAgentSearchAgent`, which gives access to `self.depth` and `self.evaluationFunction`. Make sure your minimax code makes reference to these two variables where appropriate as these variables are populated in response to command line options.

*Important:* A single search ply is considered to be one Pacman move and all the ghosts' responses, so **depth 2 search will involve Pacman and each ghost moving two times.**

*Grading:* We will be checking your code to determine whether it explores the correct number of game states. This is the only reliable way to detect some very subtle bugs in implementations of minimax.

### ***Hints and Observations***

- Hint: Implement the algorithm recursively using helper function(s).
- The correct implementation of minimax will lead to Pacman losing the game in some tests. This is not a problem: as it is correct behaviour, it will pass the tests.
- The evaluation function for the Pacman test in this part is already written (`self.evaluationFunction`). You shouldn't change this function, but recognize that now **we're evaluating *states* rather than *actions***, as we were for the reflex agent. Look-ahead agents evaluate future states whereas reflex agents evaluate actions from the current state.
- The minimax values of the initial state in the `minimaxClassic` layout are **9, 8, 7, -492 for depths 1, 2, 3 and 4 respectively.** Note that your minimax agent will often win (665/1000 games for us) despite the dire prediction of depth 4 minimax.

```
python pacman.py -p MinimaxAgent -l minimaxClassic -a\
depth=4
```

- **Pacman is always agent 0, and the agents move in order of increasing agent index.**
- All states in minimax should be `GameStates`, **either passed in to `getAction` or generated via `GameState.generateSuccessor`.** In this project, you will **not be abstracting to simplified states.**
- On larger boards such as `openClassic` and `mediumClassic` (the default), you'll find Pacman to be good at not dying, but quite bad at winning. He'll often thrash around without making progress. He might even thrash around right next to a dot without eating it because he doesn't know where he'd go after eating that dot. Don't worry if you see this behavior, question 5 will clean up all of these issues.

- When Pacman believes that his death is unavoidable, he will try to end the game as soon as possible because of the constant penalty for living. Sometimes, this is the wrong thing to do with random ghosts, but minimax agents always assume the worst:

```
python pacman.py -p MinimaxAgent -l trappedClassic -a \
depth=3
```

Make sure you understand why Pacman rushes the closest ghost in this case.

### Question 3 (5 points): Alpha-Beta Pruning

Make a new agent that uses alpha-beta pruning to more efficiently explore the minimax tree, in `AlphaBetaAgent`. Again, your algorithm will be slightly more general than the pseudocode from lecture, so part of the challenge is to extend the alpha-beta pruning logic appropriately to multiple minimizer agents.

You should see a speed-up (perhaps depth 3 alpha-beta will run as fast as depth 2 minimax) Ideally, depth 3 on `smallClassic` should run in just a few seconds per move or faster.

```
python pacman.py -p AlphaBetaAgent -a depth=3 -l smallClassic
```

The `AlphaBetaAgent` minimax values should be identical to the `MinimaxAgent` minimax values, although the actions it selects can vary because of different tie-breaking behavior. Again, the minimax values of the initial state in the `minimaxClassic` layout are 9, 8, 7 and -492 for depths 1, 2, 3 and 4 respectively.

*Grading:* Because we check your code to determine whether it explores the correct number of states, it is important that you perform alpha-beta pruning without reordering children. In other words, successor states should always be processed in the order returned by `GameState.getLegalActions`. Again, do not call `GameState.generateSuccessor` more than necessary.

The pseudo-code below represents the algorithm you should implement for this question.

### Question 4 (5 points): Expectimax

Minimax and alpha-beta are great, but they both assume that you are playing against an adversary who makes optimal decisions. As anyone who has

## Alpha-Beta Implementation

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$\alpha$ : MAX's best option on path to root  
 $\beta$ : MIN's best option on path to root

```
def max-value(state,  $\alpha$ ,  $\beta$ ):  
    initialize  $v = -\infty$   
    for each successor of state:  
         $v = \max(v, \text{value}(\text{successor}, \alpha, \beta))$   
        if  $v > \beta$  return  $v$   
         $\alpha = \max(\alpha, v)$   
    return  $v$ 
```

```
def min-value(state,  $\alpha$ ,  $\beta$ ):  
    initialize  $v = +\infty$   
    for each successor of state:  
         $v = \min(v, \text{value}(\text{successor}, \alpha, \beta))$   
        if  $v < \alpha$  return  $v$   
         $\beta = \min(\beta, v)$   
    return  $v$ 
```

ever won tic-tac-toe can tell you, this is not always the case. In this question you will implement the `ExpectimaxAgent`, which is useful for modeling probabilistic behavior of agents who may make suboptimal choices.

As with the search and constraint satisfaction problems covered so far in this class, the beauty of these algorithms is their general applicability.

Random ghosts are of course not optimal minimax agents, and so modeling them with minimax search may not be appropriate. `ExpectimaxAgent`, will no longer take the min over all ghost actions, but the expectation according to your agent's model of how the ghosts act. To simplify your code, **assume you will only be running against an adversary which chooses amongst their `getLegalActions` uniformly at random.**

To see how the `ExpectimaxAgent` behaves in Pacman, run:

```
python pacman.py -p ExpectimaxAgent -l minimaxClassic -a depth=3
```

You should now observe a more cavalier approach in close quarters with ghosts. In particular, if Pacman perceives that he could be trapped but might escape to grab a few more pieces of food, he'll at least try. Investigate the results of these two scenarios:

```
python pacman.py -p AlphaBetaAgent -l trappedClassic -a depth=3\  
-q -n 10  
python pacman.py -p ExpectimaxAgent -l trappedClassic -a depth=3\  
-q -n 10
```

You should find that your `ExpectimaxAgent` wins about half the time, while

your `AlphaBetaAgent` always loses. Make sure you understand why the behavior here differs from the minimax case.

The correct implementation of expectimax will lead to Pacman losing some of the tests. This is not a problem: as it is correct behaviour, it will pass the tests.

## Question 5 (6 points): Evaluation Function

Write a better evaluation function for pacman in the provided function `betterEvaluationFunction`. **The evaluation function should evaluate states,** rather than actions like your reflex agent evaluation function did. You may use any tools at your disposal for evaluation, including your search code from the last project. With depth 2 search, your evaluation function should clear the `smallClassic` layout with one random ghost more than half the time and still run at a reasonable rate **(to get full credit, Pacman should be averaging around 1000 points when he's winning)**.

*Grading:* OJ will run your agent on the `smallClassic` layout 10 times. We will assign points to your evaluation function in the following way:

- Win at least once without timing out the OJ
- Winning all 10 times.
- An average score of at least 1000
- Take on average less than 30 seconds on OJ

## Submission and Due Date

Submit it to online judge before due date **Jun.15**. Note you just need to compress one file in your .zip submission, `multiAgents.py`. Please do not include any other given files.