

# Multi-Agent Search

## Introduction

This exercise involves designing an agent that can play the game of Pac-man. The game involves a Pac-man (shown as a yellow circle with a mouth) that tries to eat as many food pellets (the small white dots) as possible. The Pacman must plan its actions avoiding ghosts (orange and blue agents with eyes) that are moving in the environment. There are walls present in the environment that cannot be crossed by any agent. This exercise will involve modeling the decision-making task as an adversarial search problem that allows the Pacman to decide actions while taking into account the behaviour of ghosts.

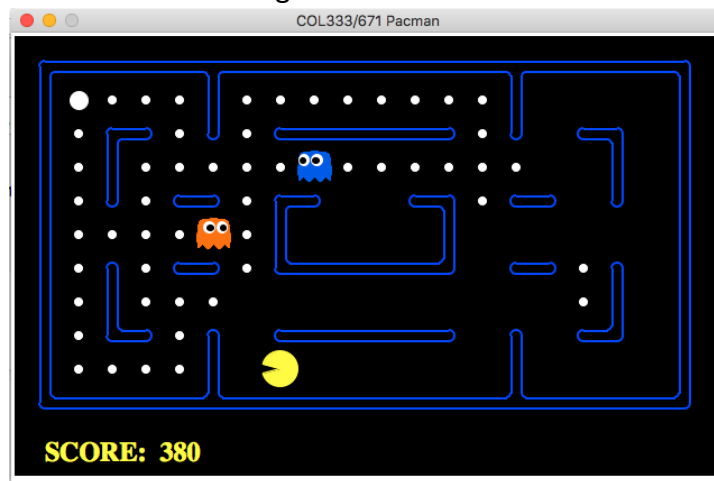


Figure: The Pacman agent (yellow) moves in a grid world with walls. The agent must eat as many food pellets as possible while avoiding ghosts (agents with eyes). Score is displayed on the bottom left. Screenshot from executing: `python pacman.py -p ReflexAgent`

## 1. Getting Started

- Download the starter code from this [link](#). The package contains starter code and supporting files to run the pacman environment. Use Python 3.6 for this assignment.
- You may create a conda environment for this assignment so that mingling with system python or any other python environment that you may already have can be avoided.
- The instructions for the first time conda installation are [here](#)). After installing conda, create an environment that uses python 3.6.

```
conda create --name col333 python=3.6
```

- You can test the above setup with the following command. The steps should display the Pacman GUI and you should be able to control the agent in the grid.

```
conda activate col333
```

```
git clone https://github.com/reail-iitd/COL333-671-2021-A1
```

```
cd COL333-671-2021-A1
```

```
python pacman.py
```

```
conda deactivate col333
```

- A simple ReflexAgent is provided in the package. The following command will invoke the ReflexAgent present in **multiAgents.py**. Running the command will invoke the default **mediumClassic** layout and display the Pacman moving in the presence of Ghosts.

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

- The ReflexAgent can be invoked in other environments such as the **testClassic** environment with the **-l** flag.

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

- Review the **ReflexAgent** code in **multiAgents.py** that provides examples to query the **GameState** for information. The **GameState** object specifies the full game state, including the food locations and the ghosts location which the Pacman needs to consider while playing the game.
- There are some sample test cases that are provided for each question which can be exercised using the commands below. These can be used while developing your solution.
- To run the autograder on all the test cases, use the following command. This will be helpful in the upcoming parts of the assignment.

```
python autograder.py # to test all test cases for each question
```

```
python autograder.py --q <question_name> # to test test cases for a particular question <question_name>
```

- We have tested the package on Ubuntu 20.04/Python 3 and Windows 10/Python 3 on a few machines. Students are requested to set up the environment on their respective machines.
- A list of options that may be useful during the assignment.

|               |   |
|---------------|---|
| --frameTime T | T=1 allows the game to be paused at every frame. T=0 Turns off animation to speed up display. |
| -g            | The default ghosts are random. The option -g can be used to invoke DirectionalGhosts.         |
| -n            | Used to play multiple games in a row.   |
| -f            | Run with a fixed random seed. This allows the same random choices in every game.              |
| -k            | Specifies the number of ghosts (should not exceed the number the layout allows).              |
| -h            | Displays options and their default values.  |

## 2. Improving the Reflex Agent [4 points]

- This part involves improving the **ReflexAgent** class in **multiAgents.py** to play better. In particular, please fill out the **evaluationFunction** in the **ReflexAgent** class.
- A capable ReflexAgent must consider both the food locations and ghost locations to perform well. Improve the **ReflexAgent** such that it can clear the **testClassic** layout.

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

- Next, try the ReflexAgent on the default **mediumClassic** layout by varying the number of ghosts. Note that there cannot be more ghosts than the number that the layout permits. The animation can be turned off to speed up the display.

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

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

- You may use the following notes/hints for this part. As features, you may try the reciprocal of important values (such as distance to food) rather than the values themselves. Please remember that **newFood** has a function **asList()**. You may view object internals by printing object internals. For example, **print(newGhostStates)** to print the **newGhostStates**.
- **Grading:** Your agent will be run on **openClassic** layout 10 times. If the agent times out or never wins then 0 points will be awarded. If the agent wins at least 5 times then 1 point will be awarded. If the agent wins all 10 times then 2 points will be awarded. If your agent's average score is greater than 500 then an additional 1 point is awarded. If the agent's score is greater than 1000 then 2 points are awarded.
- You may test your agent under the above-mentioned conditions by invoking the following the autograder. Using the **"-q"** flag makes the autograder run on a specific question as specified. Adding the **"--no-graphics"** flag disables the graphics output.

```
python autograder.py -q test_reflex
```

```
python autograder.py -q test_reflex --no-graphics
```

- Note that the evaluation function written in this part of the assignment uses the (state-action) pairs and does not perform the look ahead. Note that part 6 of this assignment will involve writing an evaluation function based on states for a game tree.

### 3. Minimax [5 points]

- Please implement an adversarial search agent in the provided **MinimaxAgent** class stub in **multiAgents.py**. The minimax agent should work with any number of ghosts, and your minimax tree should 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**. Please make sure your minimax code makes reference to these two variables where appropriate as these variables are populated in response to command line options.
- Pacman is always agent 0, and the agents move in order of increasing agent index. Note that only Pacman will be running your implementation of the MinimaxAgent.
- Note that 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.
- The minimax values of the initial state in the **minimaxClassic** layout are 9, 8, 7, -492 for depths 1, 2, 3 and 4 respectively. You can use these numbers to verify whether your implementation is correct.

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

- 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. Note that in part 6, we will work on improving the evaluation function which will improve Pacman's performance.
- Please use the evaluation function **self.evaluationFunction** provided. Do not change the function but recognize that the function is evaluating states instead of actions (which was the case for the reflex agent). Note that look-ahead agents evaluate future states whereas reflex agents evaluate actions from the current state.
- All states in minimax should be **GameState**'s, either passed in to **getAction** or generated via **GameState.generateSuccessor**. Please do not simplify the states. Please do not call the **GameState.generateSuccessor** more than necessary. You may test on a large number of games using the **-n** and **-q** flags.
- Run the command below to check if your implementation passes the default test cases in **autograder.py**. The default test cases check the exploration of the correct number of game states and examine the number of calls to the **GameState.generatedSuccessor**.

```
python autograder.py -q test_minimax  
python autograder.py -q test_minimax --no-graphics
```

- **Grading:** The autograder provided in the package tests the implementation on default test cases. The final evaluation may be done on new unseen test cases.

#### 4. Alpha-Beta Pruning [5 points]

- This part involves implementing the alpha-beta pruning technique to efficiently explore the minimax tree. The implementation is to be done in **AlphaBetaAgent**.
- Please note that the implementation must account for multiple minimizer agents.
- You may test and observe the speed up on the **smallClassic** layout with depth 3 with the following command.

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

- The implementation will be evaluated based on the exploration of the correct number of game states. Please do not reorder the child nodes in the alpha-beta pruning implementation. The successor states must always be processed in the order returned by **GameState.getLegalActions**. As before, please do not call **GameState.generateSuccessor** more than necessary.
- In this assignment, do not prune on equality, this is necessary for evaluation.
- Run the command below to check if your implementation passes the default test cases in **autograder.py**.

```
python autograder.py -q test_alpha_beta_pruning
```

- Note that the correct implementation of alpha-beta pruning will lead to Pacman losing some of the tests. As in the Minimax case, this is not a problem, as it is correct behaviour and it will pass the tests.
- **Grading:** The autograder provided in the package tests the implementation on default test cases. The final evaluation may be done on new unseen test cases.

## 5. Expectimax [5 points]

- Note that both Minimax and Alpha-beta assume that you are playing against an adversary who makes optimal decisions. Random ghosts are not optimal minimax agents and hence modeling them as Minimax agents may not be appropriate.
- In this part of the assignment, we will model the probabilistic behaviour of ghosts who may make suboptimal choices. Note that there are multiple adversaries.
- Please fill in the **ExpectimaxAgent** that will take an expectation according to your agent's model of how the ghosts act. Assume that Pacman is playing against multiple adversaries, which each chooses **getLegalActions** uniformly at random.
- Run the command below to check if your implementation passes the default test cases in **autograder.py**.

```
python autograder.py -q test_expectimax
```

- The ExpectimaxAgent can be run with the command below. You may now observe different behaviour of the **ExpectimaxAgent** when in close proximity of the ghosts that before with the **AlphaBetaAgent**. The Pacman can attempt to get more food pieces even when it could be imminently trapped with ghosts.

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

- You may try the following two scenarios and observe that the ExpectimaxAgent wins about half the time while the AlphaBetaAgent always loses.

```
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
```

- The correct implementation of expectimax will lead to Pacman losing some of the tests. This is not a problem: as it is correct behaviour and it will pass the tests.
- **Grading:** The autograder provided in the package tests the implementation on default test cases. The final evaluation may be done on new unseen test cases.

## 6. Evaluation Function [8 points]

- Please implement an improved evaluation function for the **ExpectimaxAgent**. Please fill in the provided function **betterEvaluationFunction** that estimates values for states. You can test the agent on **smallClassic** layout with the following commands:

```
python pacman.py -l smallClassic -p ExpectimaxAgent -a evalFn=better -q -n 20
```

- Run the following command to check your implementation on the default test setup.

```
python autograder.py -q test_evaluation_fn  
python autograder.py -q test_evaluation_fn --no-graphics
```

- The evaluation for this will be done in two parts: (1) Absolute component and (2) Relative component. The points obtained in both the parts will be combined appropriately.
  1. **Absolute component:** The autograder will run your agent on the **smallClassic** layout 10 times. We will assign points to your evaluation function in the following way:
    - (a) 1 point awarded if your agent wins at least once without timing out the autograder.
    - (b) +1 for winning at least 5 times and +2 for winning all 10 times.
    - (c) +1 for an average score of at least 500, +2 for an average score of at least 1000 (including scores on lost games)
    - (d) +1 if your games take on average less than 30 seconds, when run with `--no-graphics` option.
    - (e) The additional points for average score and computation time will be awarded if you win at least 5 times.
  2. **Relative component:** Your agent will be run on a new layout 10 times and assign a score as the average across these 10 runs. For grading, the final score will take into account performance by other implementations in the class.

## 7. Submission Instructions

- **This assignment is to be done individually or in pairs. The choice is yours.**
- Submit a single zip file named **<A1-EntryNumber1-EntryNumber2>.zip or <A1-EntryNumber>.zip**. Upon unzipping this should yield a single file named - **multiAgents.py**. Only one of the team members needs to submit the zip file. The assignment is to be submitted on Moodle.
- **The submission deadline is 5pm on October 07, 2021.**
- This assignment will carry 13% of the grade.
- Late submission deduction of (10% per day) will be awarded up to one additional day.
- Your code will be graded using evaluation scripts. Please do not change the names of any of the provided functions or classes within the code. Carefully follow the format. Only make changes to the two specified files and in the correct functions. Your code should use only standard python libraries (the Conda environment setup). Do not include any dependencies on third party libraries. No credit provided if you modify other functions which you are not supposed to.
- Please only submit work from your own efforts. Do not look at or refer to code written by anyone else. You may discuss the problem, however the code implementation must be original. Discussion will not be grounds to justify software plagiarism. Please do not copy existing assignment solutions from the internet or from implementations from the previous offering of this course as your submission will be compared against them using plagiarism detection software.
- Copying and cheating will result in a penalty of at least -10 (absolute). The department and institute guidelines will apply. More severe penalties such as F grade will follow.
- Remember that the autograder given to you tests your solution on default test cases. The final evaluation may be done on new unseen test cases. Therefore, you may still not receive credit even if the autograder passes on the default test cases.
- Relevant queries to be raised on Piazza.

## 8. Undertaking

The Pacman project was developed by Dan Klein at the University of California, Berkeley and is used for AI education in several universities. In order to support use of the Pacman framework for teaching in several universities, each student enrolled in COL333 and COL671 must take the following undertaking: "The Pacman project is freely available for educational use. Since the framework is used at multiple universities for AI education, it is mandated that we do not distribute or post solutions to any of the projects. Any redistribution of the code or release (e.g., on a Github account) by any student taking the course will be considered as a violation of the Honor Code in the class and will lead to penalties". A penalty will be applied if a student makes the solution available online.



## 9. List of Files in the Pacman Project

|                          |   |
|--------------------------|---|
| <b>Files to edit:</b>    |   |
| multiAgents.py           | Where all the multi-agent search agents will reside.  |
| <b>Files to look at:</b> |   |
| pacman.py                | The main file that runs Pacman games. This file describes a Pacman GameState type, which you use in this project.   |
| game.py                  | The logic behind how the Pacman world works. This file describes several supporting types like AgentState, Agent, Direction, and Grid.                            |
| util.py                  | Useful data structures for implementing search algorithms. You do not need to use these for this project, but may find other functions defined here to be useful. |
| <b>Files to ignore:</b>  |   |
| graphicsDisplay.py       | Graphics for Pacman   |
| graphicsUtils.py         | Support for Pacman graphics   |
| textDisplay.py           | ASCII graphics for Pacman   |
| ghostAgents.py           | Agents to control ghosts  |
| keyboardAgents.py        | Keyboard interfaces to control Pacman   |
| layout.py                | Code for reading layout files and storing their contents  |
| autograder.py            | Project autograder  |
| testParser.py            | Parses autograder test and solution files   |
| testClasses.py           | General autograding test classes  |
| test_cases/              | Directory containing the test cases for each question   |
| multiagentTestClasses.py | autograding test classes  |