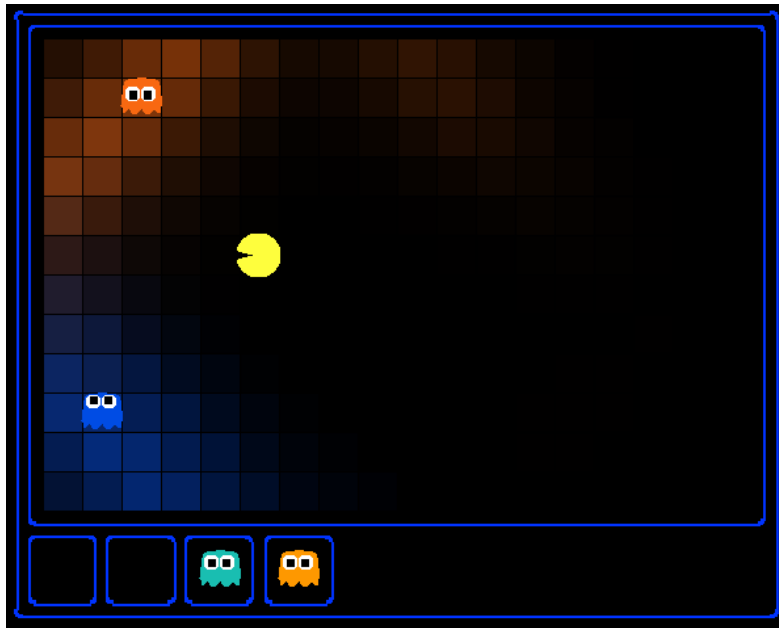


# Assignment 3: Ghostbusters

Due on: Thursday, March 6, at 11:59 p.m. (EST) (Kingston Time)



## Attribution Information:

The Pacman AI projects were developed at UC Berkeley (<http://ai.berkeley.edu>). The core projects and autograders were primarily created by John DeNero ([denero@cs.berkeley.edu](mailto:denero@cs.berkeley.edu)) and Dan Klein ([klein@cs.berkeley.edu](mailto:klein@cs.berkeley.edu)). Student side autograding was added by Brad Miller, Nick Hay, and Pieter Abbeel ([pabbeel@cs.berkeley.edu](mailto:pabbeel@cs.berkeley.edu)).

Further modifications and rubric modified for CISC 352.

## Corrections

Please check the assignment description regularly for (dated) corrections to the assignment.

## Introduction

Pacman spends his life running from ghosts, but things were not always so. Legend has it that many years ago, Pacman's great grandfather, Grandpac, learned to hunt ghosts for sport. However, he was blinded by his power and could only track ghosts by their banging and clanging. In this project, you will design Pacman agents that use sensors to locate and eat invisible ghosts. You'll advance from locating single, stationary ghosts to hunting packs of multiple moving ghosts with ruthless efficiency.

The code for this project contains the following files, available as a zip archive.

Files you'll edit:	
<code>bustersAgents.py</code>	Agents for playing the Ghostbusters variant of Pacman.
<code>solutions.py</code>	Code to implement the functionalities of <code>inference.py</code> which track ghosts over time using their sounds.
Files you will NOT edit:	
<code>inference.py</code>	Code for tracking ghosts over time using their sounds. You may refer to this file to assist your implementations in <code>solutions.py</code>
<code>busters.py</code>	The main entry to Ghostbusters (replacing <code>Pacman.py</code> )
<code>bustersGhostAgents.py</code>	New ghost agents for Ghostbusters
<code>distanceCalculator.py</code>	Computes maze distances
<code>game.py</code>	Inner workings and helper classes for Pacman
<code>ghostAgents.py</code>	Agents to control ghosts
<code>graphicsDisplay.py</code>	Graphics for Pacman

<code>graphicsUtils.py</code>	Support for Pacman graphics
<code>keyboardAgents.py</code>	Keyboard interfaces to control Pacman
<code>layout.py</code>	Code for reading layout files and storing their contents
<code>util.py</code>	Utility functions

**Files to Edit and Submit:** You will fill in the indicated part of `bustersAgents.py` and all of `solutions.py` during the assignment. Please **do not change** the other files in this distribution. Also make sure to edit/comment-out the `raiseNotDefined()` lines as you are answering the questions.

**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. We will also be giving out marks for code quality: see the rubric below for more details.

**Group Size:** This project will be done in groups of 1 - 3.

## Ghostbusters

In this version of Ghostbusters, the goal is to hunt down scared but invisible ghosts. Pacman, ever resourceful, is equipped with sonar (ears) that provides noisy readings of the Manhattan distance to each ghost. The game ends when Pacman has eaten all the ghosts. To start, try playing a game yourself using the keyboard by running:

```
python busters.py
```

The blocks of color indicate where each ghost could possibly be, given the noisy distance readings provided to Pacman. The noisy distances at the bottom of the display are always non-negative, and always within 7 of the true distance. The probability of a distance reading decreases exponentially with its difference from the true distance.

Your primary task in this project is to implement inference to track the ghosts. For the keyboard-based game above, a crude form of inference was implemented for you by default: all squares

in which a ghost could possibly be are shaded by the color of the ghost. Naturally, we want a better estimate of the ghost's position.

While watching and debugging your code with the autograder, it will be helpful to have some understanding of what the autograder is doing. There are 2 types of tests in this project, as differentiated by their .test files found in the subdirectories of the test\_cases folder. For tests of class DoubleInferenceAgentTest, you will see visualizations of the inference distributions generated by your code, but all Pacman actions will be pre-selected according to the actions of the staff implementation. This is necessary to allow comparison of your distributions with the staff's distributions. The second type of test is GameScoreTest, in which your BustersAgent will actually select actions for Pacman, and you will watch your Pacman play and win games.

As you implement and debug your code, you may find it useful to run a single test at a time. In order to do this, you will need to use the -t flag with the autograder. For example, if you only want to run the first test of question 2, use:

```
python autograder.py -t test_cases/q2/1-ObsProb
```

In general, all test cases can be found inside test\_cases/q\*.

For this project, it is possible sometimes for the autograder to time out if running the tests with graphics. To accurately determine whether your code is efficient enough, you should run the tests with the

```
--no-graphics
```

flag. If the autograder passes with this flag, then you will receive full points, even if the autograder times out with graphics.

**\*IMPORTANT\*:** You may not use random.choices() and its weighted selection in any of your implementation.

**Note:** Questions 1-4 will be coded in solutions.py, but you may refer to inference.py to see the class structures and determine how to complete the implementation.

## Question 1 (0.5 points): DiscreteDistribution Class

Throughout this project, we will be using the DiscreteDistribution class defined in inference.py to model belief distributions and weight distributions. This class is an extension of the built-in Python dictionary class, where the keys are the different discrete elements of our distribution, and the corresponding values are proportional to the belief or weight that the distribution assigns that element. This question asks you to fill in the missing parts of this class through solutions.py. These methods will be crucial for later questions.

First, fill in the `normalize` method, which normalizes the values in the distribution to sum to one, but keeps the proportions of the values the same. Use the `total` method to find the sum of the values in the distribution. For an empty distribution or a distribution where all of the values are zero, do nothing. Note that this method modifies the distribution directly, rather than returning a new distribution.

Second, fill in the `sample` method, which draws a sample from the distribution, where the probability that a key is sampled is proportional to its corresponding value. Assume that the distribution is not empty, and not all of the values are zero. Note that the distribution does not necessarily have to be normalized prior to calling this method. You may find Python's built-in `random.random()` function useful for this question.

There are no autograder tests for this question, but the correctness of your implementation can be easily checked. We have provided Python doctests as a starting point, and you can feel free to add more and implement other tests of your own. You can run the doctests using:

```
python -m doctest -v inference.py
```

Note that, depending on the implementation details of the `sample` method, some correct implementations may not pass the doctests that are provided. To thoroughly check the correctness of your `sample` method, you should instead draw many samples and see if the frequency of each key converges to be proportional of its corresponding value.

## Question 2 (0.5 points): Observation Probability

In this question, you will implement the `getObservationProb` method in `solutions.py` that is called from the `InferenceModule` base class in `inference.py`. This method takes in an observation (which is a noisy reading of the distance to the ghost), Pacman's position, the ghost's position, and the position of the ghost's jail, and returns the probability of the noisy distance reading given Pacman's position and the ghost's position. In other words, we want to return  $P(\text{noisyDistance} \mid \text{pacmanPosition}, \text{ghostPosition})$ .

The distance sensor has a probability distribution over distance readings given the true distance from Pacman to the ghost. This distribution is modeled by the function `busters.getObservationProbability(noisyDistance, trueDistance)`, which returns  $P(\text{noisyDistance} \mid \text{trueDistance})$  and is provided for you. You should use this function to help you solve the problem, and use the provided `manhattanDistance` function to find the distance between Pacman's location and the ghost's location.

However, there is the special case of jail that we have to handle as well. Specifically, when we capture a ghost and send it to the jail location, our distance sensor deterministically returns `None`, and nothing else. So, if the ghost's position is the jail position, then the observation is `None` with probability 1, and everything else with probability 0. Conversely, if the distance reading is not `None`, then the ghost is in jail with probability 0. If the distance reading is `None`

then the ghost is in jail with probability 1. Make sure you handle this special case in your implementation.

To test your code and run the autograder for this question:

```
python autograder.py -q q2
```

As a general note, it is possible for some of the autograder tests to take a long time to run for this project, and you will have to exercise patience. As long as the autograder doesn't time out, you should be fine (provided that you actually pass the tests).

### Question 3 (0.5 points): Exact Inference Observation

In this question, you will implement the `observeUpdate` method in `solutions.py` that is called from the `ExactInference` class of `inference.py` to correctly update the agent's belief distribution over ghost positions given an observation from Pacman's sensors. You are implementing the online belief update for observing new evidence. The `observeUpdate` method should, for this problem, update the belief at every position on the map after receiving a sensor reading. You should iterate your updates over the variable `self.allPositions` which includes all legal positions plus the special jail position. Beliefs represent the probability that the ghost is at a particular location, and are stored as a `DiscreteDistribution` object in a field called `self.beliefs`, which you should update.

Before typing any code, write down the equation of the inference problem you are trying to solve. You should use the function `self.getObservationProb` that you wrote in the last question, which returns the probability of an observation given Pacman's position, a potential ghost position, and the jail position. You can obtain Pacman's position using `gameState.getPacmanPosition()`, and the jail position using `self.getJailPosition()`.

In the Pacman display, high posterior beliefs are represented by bright colors, while low beliefs are represented by dim colors. You should start with a large cloud of belief that shrinks over time as more evidence accumulates. As you watch the test cases, be sure that you understand how the squares converge to their final coloring.

Note: your busters agents have a separate inference module for each ghost they are tracking. That's why if you print an observation inside the `observeUpdate` function, you'll only see a single number, even though there may be multiple ghosts on the board.

To run the autograder for this question and visualize the output:

```
python autograder.py -q q3
```

If you want to run this test (or any of the other tests) without graphics you can add the following flag:

```
python autograder.py -q q3 --no-graphics
```

**\*IMPORTANT\*:** In general, it is possible sometimes for the autograder to time out if running the tests with graphics. To accurately determine whether or not your code is efficient enough, you should run the tests with the `--no-graphics` flag. If the autograder passes with this flag, then you will receive full points, even if the autograder times out with graphics.

## Question 4 (0.5 points): Exact Inference with Time Elapse

In the previous question, you implemented belief updates for Pacman based on his observations. Fortunately, Pacman's observations are not his only source of knowledge about where a ghost may be. Pacman also has knowledge about the ways that a ghost may move; namely that the ghost cannot move through a wall or more than one space in one time step.

To understand why this is useful to Pacman, consider the following scenario in which there is Pacman and one Ghost. Pacman receives many observations which indicate the ghost is very near, but then one which indicates the ghost is very far. The reading indicating the ghost is very far is likely to be the result of a buggy sensor. Pacman's prior knowledge of how the ghost may move will decrease the impact of this reading since Pacman knows the ghost could not move so far in only one move.

In this question, you will implement the `elapseTime` method in `solutions.py` that is called from `ExactInference`. The `elapseTime` step should, for this problem, update the belief at every position on the map after one time step elapsing. Your agent has access to the action distribution for the ghost through `self.getPositionDistribution`. In order to obtain the distribution over new positions for the ghost, given its previous position, use this line of code:

```
newPosDist = self.getPositionDistribution(gameState, oldPos)
```

Where `oldPos` refers to the previous ghost position. `newPosDist` is a `DiscreteDistribution` object, where for each position `p` in `self.allPositions`, `newPosDist[p]` is the probability that the ghost is at position `p` at time `t + 1`, given that the ghost is at position `oldPos` at time `t`. Note that this call can be fairly expensive, so if your code is timing out, one thing to think about is whether or not you can reduce the number of calls to `self.getPositionDistribution`.

Before typing any code, write down the equation of the inference problem you are trying to solve. In order to test your predict implementation separately from your update implementation in the previous question, this question will not make use of your update implementation.

Since Pacman is not observing the ghost, this means the ghost's actions will not impact Pacman's beliefs. Over time, Pacman's beliefs will come to reflect places on the board where he believes ghosts are most likely to be given the geometry of the board and what Pacman already knows about their valid movements.

For the tests in this question, we will sometimes use a ghost with random movements and other times we will use the `GoSouthGhost`. This ghost tends to move south so over time, and without

any observations, Pacman's belief distribution should begin to focus around the bottom of the board. To see which ghost is used for each test case you can look in the .test files.

To run the autograder for this question and visualize the output:

```
python autograder.py -q q4
```

If you want to run this test (or any of the other tests) without graphics you can add the following flag:

```
python autograder.py -q q4 --no-graphics
```

**\*IMPORTANT\*:** In general, it is possible sometimes for the autograder to time out if running the tests with graphics. To accurately determine whether or not your code is efficient enough, you should run the tests with the `--no-graphics` flag. If the autograder passes with this flag, then you will receive full points, even if the autograder times out with graphics.

As you watch the autograder output, remember that lighter squares indicate that Pacman believes a ghost is more likely to occupy that location, and darker squares indicate a ghost is less likely to occupy that location. For which of the test cases do you notice differences emerging in the shading of the squares? Can you explain why some squares get lighter and some squares get darker?

## Question 5 (0.5 points): Exact Inference Full Test

Now that Pacman knows how to use both his prior knowledge and his observations when figuring out where a ghost is, he is ready to hunt down ghosts on his own. This question will use your `observeUpdate` and `elapsedTime` implementations together, along with a simple greedy hunting strategy which you will implement for this question. In the simple greedy strategy, Pacman assumes that each ghost is in its most likely position according to his beliefs, then moves toward the closest ghost. Up to this point, Pacman has moved by randomly selecting a valid action.

Implement the `chooseAction` method in `GreedyBustersAgent` in `bustersAgents.py`. Your agent should first find the most likely position of each remaining uncaptured ghost, then choose an action that minimizes the maze distance to the closest ghost.

To find the maze distance between any two positions `pos1` and `pos2`, use `self.distancer.getDistance(pos1, pos2)`. To find the successor position of a position after an action:

```
successorPosition = Actions.getSuccessor(position, action)
```

You are provided with `livingGhostPositionDistributions`, a list of `DiscreteDistribution` objects representing the position belief distributions for each of the ghosts that are still uncaptured.



If correctly implemented, your agent should win the game in q4/3-gameScoreTest with a score greater than 700 at least 8 out of 10 times. Note: the autograder will also check the correctness of your inference directly, but the outcome of games is a reasonable sanity check.

To run the autograder for this question and visualize the output:

```
python autograder.py -q q5
```

If you want to run this test (or any of the other tests) without graphics you can add the following flag:

```
python autograder.py -q q5 --no-graphics
```

**\*IMPORTANT\*:** In general, it is possible sometimes for the autograder to time out if running the tests with graphics. To accurately determine whether or not your code is efficient enough, you should run the tests with the `--no-graphics` flag. If the autograder passes with this flag, then you will receive full points, even if the autograder times out with graphics.

## Rubric

This assignment will be scored out of 3, as follows:

	0	0.15	0.3	0.5
<b>Code Quality</b>	Code is unclear and/or difficult to understand	Code is generally well-written with some awkward or unclear elements	Code is clear, efficient, well-written, but poorly-commented/not commented	Code is clear, efficient, well-written, and well-commented
<b>Question 1</b>	Both methods have significant errors	Only one of the two methods work, and the other has significant errors  OR  Both have minor errors	One method works and the other has minor errors	<i>sample</i> and <i>normalize</i> methods are implemented correctly
<b>Question 2</b>	Both <code>getObservationProb</code> and special case have significant errors	<code>getObservationProb</code> implemented correctly, but special case has significant errors,	<code>getObservationProb</code> implemented correctly, but special case has minor errors, or	<code>getObservationProb</code> implemented correctly

		or vice versa  OR  Both getObservationPr ob and special case have minor errors	vice versa	
<b>Question 3</b>	observeUpdate implemented incorrectly, but a reasonable attempt was made	observeUpdate implemented correctly but with significant flaws, such as not updating beliefs	observeUpdate has minor errors	observeUpdate implemented correctly
<b>Question 4</b>	elapsedTime implemented incorrectly, but a reasonable attempt was made	elapsedTime implemented correctly but with significant flaws, such as not updating beliefs	elapsedTime has minor errors	elapsedTime method implemented correctly
<b>Question 5</b>	chooseAction implemented incorrectly, but a reasonable attempt was made	chooseAction has major errors (ex. chooses an action but not one based on the most likely ghost positions)	chooseAction implemented with minor errors (ex. chooses an action that minimizes the distance to a ghost but not the closest one)	chooseAction implemented correctly

Leaving a question blank or entering something irrelevant for a question will result in a mark of 0 for that question.

## Submission

In addition to the two files, busterAgents.py and solutions.py, prepare a short document that lists the contributions of each member. It can be either .txt, .docx, or .pdf. Put the two files and the document into a zip file, and have one member of your group submit the zip file before the due date in the Assignment 3 drop box on onQ.