# Homework 1: Search

*Artificial Intelligence, Spring 2015*

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*due date:* Friday, February 13th, 2015, at 11:00pm

**Abstract**

For this assignment, students will implement search algorithms including Breadth First Search, Depth First Search, and A* Search. They will apply these algorithms to a variety of problems to examine the strengths and weaknesses of each algorithm. Then they will answer a set of questions about their observations, including both practical and theoretical analysis of the algorithms involved.

# 1 Instructions

Please read the directions of this assignment carefully, and follow them. Failure to follow directions will result in lost points. All work must be submitted through Blackboard and before the due date to be considered for grading (baring extensions).

All portions of this assignment are to be completed by all students unless otherwise noted. Requirements that are specific to students enrolled in 600.435 will be specified in the form ***435 only:*** *implement feature x*. Students enrolled in 600.335 are not required to complete these portions of the assignment, and will not receive extra credit for doing so. If you have questions or concerns about any of the requirements, please contact the TA or the instructor as soon as possible.

Students are strongly encouraged to use the Java programming language for this assignment. The instructions below are written to allow for the use of other languages, but several assignments will come with scaffolding (i.e. partial implementations of a problem solution) in Java so that students do not have to implement certain things which would be time-consuming and are unrelated to AI. If you wish to use a different language, please discuss your plan with the instructor before beginning to work on your implementation.

## 1.1 Submission Contents

This homework consists of two parts, a programming portion and a written portion. The entire assignment should be submitted as a tarball through Blackboard. When extracted, your tarball should produce the following directory structure. All your submitted work should be in a top-level directory named '`<lastname>.<firstname>/`', with your name inserted, all lower case (for example, `mitchell.ben/`). That directory should contain the following subdirectories: `src/, doc/, data/, output/, bin/, [include/], [lib/]`. The directories in brackets are optional; use them if appropriate for your implementation. The proper use of these directories is described below.

`src/` should contain all your source code

`doc/` should contain all documentation and source for documentation (if applicable; eg. *.tex files).

`data/` should contain all data, problem instances, or other files that are read as input by your program.

`output/` should contain sample runs showing the behavior of your program.

`bin/` should contain all binary executable files (it should be empty in your tarball; don't include binaries, just make sure they get put in `bin/` when they get built).

[`include/` ] should contain header files (eg. if you are using C/C++, you may wish to have .h files in `include/` and .c files in `src/`.

[`lib/` ] should contain any libraries your code requires to link/run. You are not expected to generate your own libraries (eg. libfoo.a) as a part of the assignment, though you may do so if you wish. Any outside libraries used must by properly cited in your README.

The top level directory should also contain an ASCII text file named `'README'`. Your README should contain your name, the name of the course, and the title of the assignment (which is also the title of this document). It should include a listing of the files in your submission, with a very brief description of what each file contains. It should describe the structure and organization of your code, as well as describing in detail how to build and run your program (ie. what arguments does it take/expect, what is the interface if the program is interactive, how to make your program use a particular problem instance, etc.). It should also list approximate runtimes for all the problem instances specified in the assignment.

Your README should also have a section entitled "Refelections" at the end, which should contain a paragraph or two of text describing your thoughts about the assignment. It should contain an estimate of how much time you spent on the assignment, along with your thoughts about things like what parts you liked or didn't like, what parts you found particularly hard or easy, what you felt like you learned, or how you would change the assignment if you were in charge of creating assignments for the class. You don't have to limit yourself to these things, nor do you need to discuss every single one of them for every program; pick the ones that have interesting examples (but be sure to always include how long the homework took you to complete).

The "sample program runs" in the `output/` directory should be transcripts of your program's output. It should be clear from the output which problem instance was used for a given run. For most assignments, it should be sufficient to copy and paste the text from the terminal in which you ran your program to a text editor. Alternatively, you may wish to redirect `stdout` and/or `stderr` to a file.

## 1.2 Program Requirements

For the programming portion, all code must build and run on the ugrad linux machines, and they must be buildable/runnable using command line tools. Where and how you develop are up to you so long as the code you turn in satisfies these requirements. You should include shell scripts called `compile.sh` and `run.sh` that compile and run your program, respectively. If you are using a language that does not require compilation, the `compile.sh` script can simply be a placeholder that does something like ‘`echo "No compilation required"`‘, but it must still be included in your submission. These scripts should be in the top level directory. If you are unfamiliar with shellscripting, there are many resources online, and you are welcome as always to ask questions of the TA or the instructor. Additionally, you are free to discuss scripting issues on the Blackboard discussion forum, where a topic has been created specifically for this subject. These scripts are not considered to be a part of your implementation of an algorithm, and therefore you may discuss them in any detail you wish, including posting code or examples (if you are unsure if a given post is appropriate, send it to the instructor or TA as a private message, and we will let you know).

Code will be graded based on style as well as correctness. You are expected to write well documented, well structured, readable code. The industry best practices for the language you are using is a good reference. The exact specification of what is desirable will depend on the language you are using, but in addition to good documentation, code should have good modular design and be written in a way that makes reading and understanding what it is doing as easy as possible. For Java, you should follow the standard code conventions (`http://www.oracle.com/technetwork/java/javase/documentation/codeconvtoc-136057.html`). This includes proper use of packages and JavaDoc comments.

Code will also be graded based on efficiency of implementation. This does not mean that you are expected to write heavily optimized systems-level code, but rather that your implementations should be reasonably efficient. If your implementation of an $O(n)$ algorithm takes $O(2^n)$ time to run, for example, it will be penalized as a poor implementation of that algorithm. You will not be penalized for your language choice except to the extent that if your program is unable to solve the given problems before the assignment is due, you will be unable to get full credit for having completed those problems (since there is no way to prove that the answer would have been correct, and you will be unable to answer the written problems related to those solutions). Additionally, if you choose a language other than Java, you will be unable to use any code which is provided with the assignment, and must write the equivalent code in your language of choice yourself.

Any generated documentation related to code (eg. JavaDoc, doxygen, etc.) should be located in your `doc/` subdirectory, and described in your README.

## 1.3 Writeup Requirements

Your writeup document should be located in the `doc/` subdirectory. It should be a PDF document with 12 point, single spaced text. I encourage the use of LaTeXto generate your writeup, but any program is fine so long as you can generate a PDF. Any non-PDF files in your `doc/` directory (eg. MSWord files, LaTeXsource files, etc.) will not be used in grading, though their presence will not be counted against you. The reason for this is that

PDFs render and print the same way on all platforms, and can be read using free software. Additionally, PDFs can be created using free software, so no financial burden is incured by standardizing to this format.

Unless otherwise specified, each question should be answered in complete, well formed English sentences.

Links to information about LaTeXcan be found on the instructor's website, `http://cs.jhu.edu/~ben/latex/` for those that are interested. Additionally, the LaTeXsource for this assignment will be provided on Blackboard, along with the other files required to build this PDF.

# 2 Programming Assignment

For this assignment, you will implement a basic search algorithm, and several different search strategies that work with it. The strategies you are required to implement are **Breadth First Search** (BFS), **Depth First Search** (DFS), and **A* search**. For A*, you must also implement non-trivial admissible heuristics for the given problems. You may re-use the same heuristic for multiple problem instances, but you are not required to do so.

***435 only:*** *435 students must implement* ***iterative deepening depth-first search*** *and* ***bi-directional search*** *as well.*

You will be provided with a very basic scaffold for this assignment; it does not provide any useful Java code, but does demonstrate proper directory structure, correct use of Java packages, and an example of one way to create scripts to build and run your program.

Your program must be able to take as input the provided data files, the format of which will be described in detail below. Your program should output a list of the actions along the path from the start to the goal found by your search algorithm, along with the total cost of that path, and the total number of nodes expanded during the search process. If there exists no path to a goal, your program should output a message stating that instead of the path, and a cost of infinity. It should still report the number of nodes expanded. A user should be able to specify at runtime which search strategy should be used (command line arguments are fine, or a text based UI; no GUI is expected).

The problems your program will be expected to solve will be instances of path planning in a rectangular grid-world. Data files for the gridworld problems will be flat ASCII text files. The first line will contain the width and the height of the world (or map), separated by whitespace. The rest of the file will be a 2d representation of the map, with open squares (ie. squares the agent may move into) represented by a period (`'.'`) or a comma (`','`), squares with an obstacle (ie. squares the agent may not move into) represented by a pound symbol (`'#'`), the start state marked with an `'s'`, and the goal state marked with a `'g'`. The actions that are available for this problem are movement in any of the 4 cardinal directions, subject to the constraint that movement into a square with an obstacle is not allowed. Movement into a square marked with a period has a cost of one (regardless of what type of square you are moving from); movement into a square marked with a comma has a cost of two (regardless of what type of square you are moving from). Moving into the start or the goal state has a cost of one.

In the following very simple example, there is only one path to the goal, and it requires taking 7 steps to the right.

"map1.txt"

```
10 3
##########
#s......g#
##########
```

# 3 Problem Instances

**Note:** these are verbal descriptions of problems that are formally specified in the data files that are distributed with this assignment.

**1.** `map1.txt` A very small map with a straight corridor of width 1 connecting the start and the goal.

**2.** `map2.txt` A slightly larger map with an inverted-L shaped corridor connecting the start and the goal.

**3.** `map3.txt` A 10×10 map, this time the path to the goal is more complicated and there are several wrong turns possible.

**4.** `map4.txt` A 12×12 map, with several loops an agent can get stuck in.

**5.** `map5.txt` A 10×10 map, this time of a more open environment rather than a narrow-corridor maze, and introducing different types of terrain.

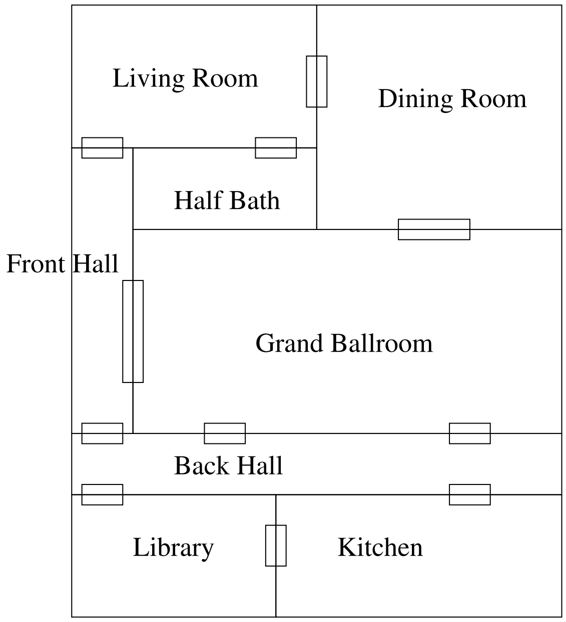
**6.** `map6.txt` A 100×10000 map, with a completely open environment (no obstacles but the edges of the map). The size of this map will help you test the ability of your search strategies to scale well.

**7.** `map7.txt` A 10×10 map, but this time the goal is completely inaccessible. Success is not possible, but failure modes are interesting properties of different search strategies.

**8.** `map8.txt` A 10×10 map, with two paths to the goal. One has fewer steps and is more direct, but the other has a lower total path cost.

# 4 Written Questions

For questions 1 through 4, consider the following search problem. A robot is in the dining room, when its owner asks it to go and get her a beer so she doesn't have to get up from the table. The program controlling the robot knows some information about the layout of the house, and how to get from location to location, but needs to plan a path that will take it from its current location (in the dining room) to the kitchen (where the fridge with the beer is).




The agent has this map of the house, and knows how to move between rooms. The costs for moving between each pair of rooms with a door connecting them are listed in the following table. The costs are the same for the reverse directions (ie. the cost of going from A to B is the same as the cost of going from B to A), so only one direction is specified.

| | | Cost |
|---|---|---|
| Living Room | Dining Room | 1 |
| Living Room | Front Hall | 2 |
| Living Room | Half Bath | 1 |
| Front Hall | Back Hall | 2 |
| Front Hall | Grand Ballroom | 1 |
| Dining Room | Grand Ballroom | 2 |
| Back Hall | Grand Ballroom | 1 |
| Back Hall | Library | 1 |
| Back Hall | Kitchen | 2 |
| Library | Kitchen | 2 |

The relevant state consists of what room the agent is currently in. The start state is the agent being in the dining room, and the goal is the agent being in the kitchen. The actions available to the agent and their costs are defined by the above table. Assume that the agent orders its node evaluations by starting a sweep at 12 o'clock and proceeding in a counter-clockwise fashion, evaluating each doorway the sweep crosses in order.

**1.** Draw a graph of the *state-space* for this search problem. Be sure to include and label all nodes with appropriate names and all edges with the correct weights. Note the total cost of the path found.

**2.** Draw a graph of the *search tree* that will be created if the agent uses the Depth First Seach strategy to solve this problem. Draw only nodes of the tree that will actually be expanded in the course of the search. Note the total cost of the path found.

**3.** Draw a graph of the search tree that will be created if the agent uses the Breadth First Search strategy to solve this problem. Draw only nodes of the tree that will actually be expanded in the course of the search. Note the total cost of the path found.

**4.** Draw a graph of the search tree that will be created if the agent uses the Uniform Cost Search strategy to solve this problem. Draw only nodes of the tree that will actually be expanded in the course of the search. Note the total cost of the path found.

## The following questions are based on your implementation for the programming portion of the assignment:

**5.** With respect to your program implementation, create a table listing the number of nodes expanded by each search algorithm for each of the gridworld problems, as well as the approximate runtime (use the `time` command, and report `user` time), and the total cost of the path to the goal that was found. Note that timing information is useful only for very rough relative comparisons, and is not a useful metric for rigorous analysis. If your program failed to find a solution, report how it failed. The table should look something like the following, only with all the maps, and with the numbers filled in. Also note that students in 435 should include all the algorithhms they implemented.

| | **BFS:** | nodes | time | cost | **DFS:** | nodes | time | cost | **A*:** | nodes | time | cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Map 1 | | $x$ | $y$ | $z$ | | $x'$ | $y'$ | $z'$ | | $x''$ | $y''$ | $z''$ |
| Map 2 | | $p$ | $q$ | $r$ | | $p'$ | $q'$ | $r'$ | | $p''$ | $q''$ | $r''$ |
| .<br>.<br>. | | .<br>.<br>. | .<br>.<br>. | .<br>.<br>. | | .<br>.<br>. | .<br>.<br>. | .<br>.<br>. | | .<br>.<br>. | .<br>.<br>. | .<br>.<br>. |

**6.** Describe the A* heuristic you chose for the gridworld problems. Justify its admissibility and discuss its usefulness in solving these problems, in particular the later ones.

**7.** Give an example of a problem where basic BFS would succeed but basic DFS would fail. Describe why this example would cause this behavior.

**8.** Give an example of a problem where basic DFS would succeed but basic BFS would fail. Describe why this example would cause this behavior.

**9.** Give an example of a problem where A* will not show improved performance over BFS. Describe why this example would cause this behavior.

**10.** For each of the following heuristics for the gridworld map problems (as specified in the assignment), state whether the heuristic is admissible, and then whether it is useful (ie. how good a job does it do of allowing us to expand as few nodes as possible before finding the goal). Justify your response.

- $h(n) = 2$ for all $n$
- $h(n) = 0$ if $n$ is the goal, 1 otherwise
- $h(n) =$ Euclidean distance from current node to goal node
- $h(n) =$ Twice the Euclidean distance from current node to goal node
- $h(n) =$ Manhattan distance from current node to goal node
- $h(n) =$ One half the Manhattan distance from current node to goal node

**11.** ***435 only****: answer the following question:*

For long-distance path planning for aircraft, the Euclidean distance between the 3D coordinates of two locations is not admissible. Discuss why this is the case, and give an example of a better heuristic to use.