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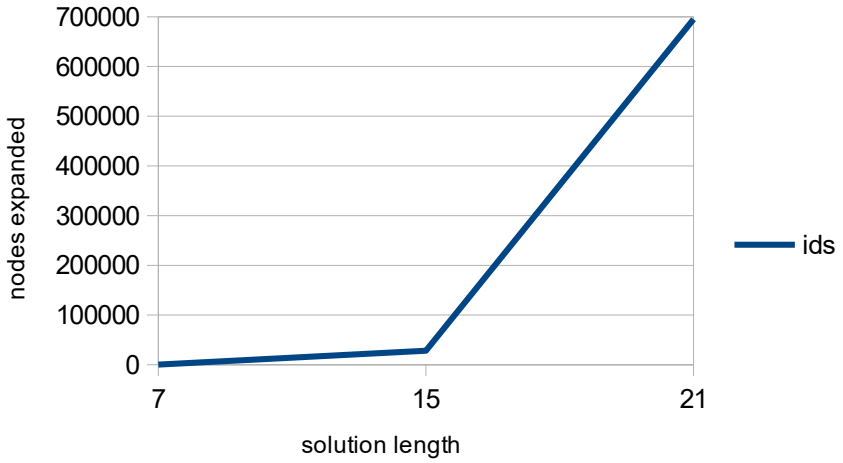
CS 470, section 001

Programming Assignment (Deterministic Search)

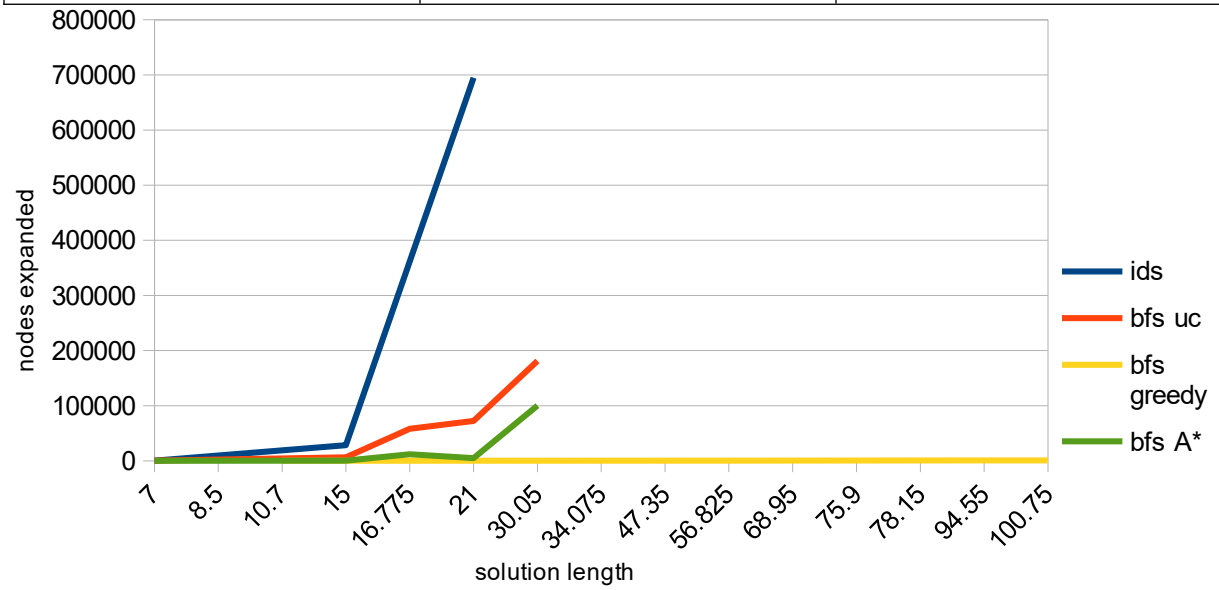
Task 1.2:
python eight.py ___.txt

```
Solved 40 puzzles from file:  easy.txt
Average nodes expanded:  334.1
Average search time:  0.006458097696304321
Average solution length:  7.0
///
Solved 40 puzzles from file:  medium.txt
Average nodes expanded:  28269.0
Average search time:  0.3514295816421509
Average solution length:  15.0
///
Solved 40 puzzles from file:  hard.txt
Average nodes expanded:  695113.1
Average search time:  7.703120929002762
Average solution length:  21.0
///
worst.txt: Too long.
///
random.txt: Too long.
```



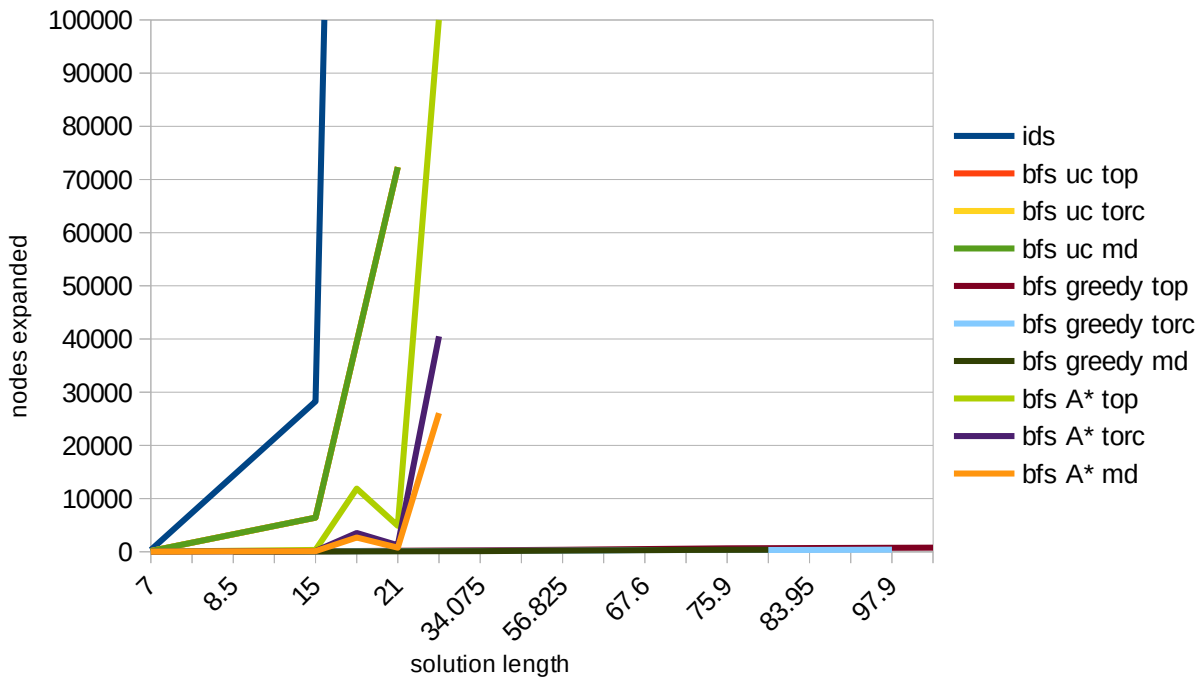
Task 1.3:
python eight.py ___.txt -s bfs -t _

1. u	2. g	3. a
Solved 40 puzzles from file: easy.txt Average nodes expanded: 143.7 Average search time: 0.002734261751174927 Average solution length: 7.0 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 6407.25 Average search time: 0.1732851445674896 Average solution length: 15.0 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 72320.5 Average search time: 2.857686048746109 Average solution length: 21.0 /// Solved 40 puzzles from file: worst.txt Average nodes expanded: 181315.7 Average search time: 11.154147070646285 Average solution length: 30.05 /// Solved 40 puzzles from file: random.txt Average nodes expanded: 58265.65 Average search time: 2.8835142612457276 Average solution length: 16.775	Solved 40 puzzles from file: easy.txt Average nodes expanded: 52.675 Average search time: 0.0011720776557922364 Average solution length: 10.7 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 624.8 Average search time: 0.01435028314590454 Average solution length: 75.9 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 716.2 Average search time: 0.0167940616607666 Average solution length: 94.55 /// Solved 40 puzzles from file: worst.txt Average nodes expanded: 771.55 Average search time: 0.019334781169891357 Average solution length: 100.75 /// Solved 40 puzzles from file: random.txt Average nodes expanded: 363.175 Average search time: 0.009648030996322632 Average solution length: 56.825	Solved 40 puzzles from file: easy.txt Average nodes expanded: 13.35 Average search time: 0.0003902614116668701 Average solution length: 7.0 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 341.175 Average search time: 0.00898277759552002 Average solution length: 15.0 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 4887.875 Average search time: 0.12544544339179992 Average solution length: 21.0 /// Solved 40 puzzles from file: worst.txt Average nodes expanded: 100266.5 Average search time: 3.328859108686447 Average solution length: 30.05 /// Solved 40 puzzles from file: random.txt Average nodes expanded: 11867.425 Average search time: 0.35192922353744505 Average solution length: 16.775



Task 1.5:
python eight.py ___.txt -s bfs -f ___ -t _

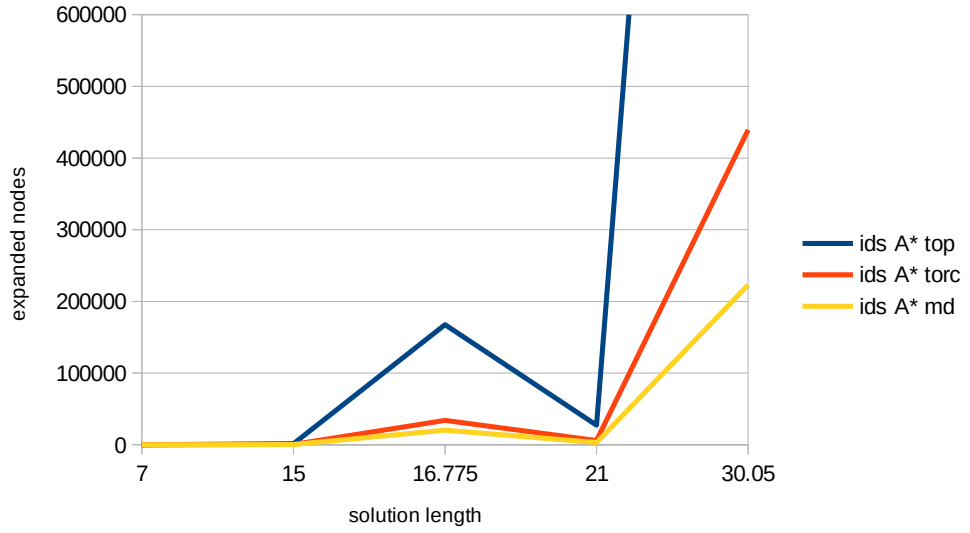
	Uniform Cost (-t u)	Greedy (-t g)	A* (-t a)
Out Of Place (-f top)	Solved 40 puzzles from file: easy.txt Average nodes expanded: 143.7 Average search time: 0.003397214412689209 Average solution length: 7.0 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 6407.25 Average search time: 0.17597563266754152 Average solution length: 15.0 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 72320.5 Average search time: 2.7566242933273317 Average solution length: 21.0 /// worst.txt: Too long. /// random.txt: Too long.	Solved 40 puzzles from file: easy.txt Average nodes expanded: 52.675 Average search time: 0.0015218853950500488 Average solution length: 10.7 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 624.8 Average search time: 0.015580534934997559 Average solution length: 75.9 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 716.2 Average search time: 0.017748379707336427 Average solution length: 94.55 /// Solved 40 puzzles from file: worst.txt Average nodes expanded: 771.55 Average search time: 0.01885782480239868 Average solution length: 100.75 /// Solved 40 puzzles from file: random.txt Average nodes expanded: 363.175 Average search time: 0.009101653099060058 Average solution length: 56.825	Solved 40 puzzles from file: easy.txt Average nodes expanded: 13.35 Average search time: 0.0004747450351715087 7 Average solution length: 7.0 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 341.175 Average search time: 0.00851036310195923 Average solution length: 15.0 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 4887.875 Average search time: 0.12726954221725464 Average solution length: 21.0 /// Solved 40 puzzles from file: worst.txt Average nodes expanded: 100266.5 Average search time: 3.379349720478058 Average solution length: 30.05 /// Solved 40 puzzles from file: random.txt Average nodes expanded: 11867.425 Average search time: 0.35470956563949585 Average solution length: 16.775
Out Of Row+Column (-f torc)	Solved 40 puzzles from file: easy.txt Average nodes expanded: 143.7 Average search time: 0.006241744756698609 Average solution length: 7.0 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 6407.25 Average search time: 0.30295884013175967 Average solution length: 15.0 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 72320.5 Average search time: 4.40437838435173 Average solution length: 21.0 /// worst.txt: Too long. /// random.txt: Too long.	Solved 40 puzzles from file: easy.txt Average nodes expanded: 12.6 Average search time: 0.0006503403186798095 Average solution length: 7.55 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 314.65 Average search time: 0.013648778200149536 Average solution length: 67.6 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 354.2 Average search time: 0.015412580966949464 Average solution length: 83.95 /// Solved 40 puzzles from file: worst.txt Average nodes expanded: 405.525 Average search time: 0.0178511381149292 Average solution length: 97.9 /// Solved 40 puzzles from file: random.txt Average nodes expanded: 247.05 Average search time: 0.010746759176254273 Average solution length: 56.925	Solved 40 puzzles from file: easy.txt Average nodes expanded: 10.0 Average search time: 0.0005527198314666748 Average solution length: 7.0 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 130.0 Average search time: 0.005998432636260986 Average solution length: 15.0 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 1225.05 Average search time: 0.056196081638336184 Average solution length: 21.0 /// Solved 40 puzzles from file: worst.txt Average nodes expanded: 40513.3 Average search time: 2.0192739069461823 Average solution length: 30.05 /// Solved 40 puzzles from file: random.txt Average nodes expanded: 3531.8 Average search time: 0.1645221710205078 Average solution length: 16.775
Manhattan (-f md)	Solved 40 puzzles from file: easy.txt Average nodes expanded: 143.7 Average search time: 0.005340993404388428 Average solution length: 7.0 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 6407.25 Average search time: 0.2584782361984253 Average solution length: 15.0 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 72320.5 Average search time: 3.90814493894577 Average solution length: 21.0 /// worst.txt: Too long. /// random.txt: Too long.	Solved 40 puzzles from file: easy.txt Average nodes expanded: 14.25 Average search time: 0.0006896734237670898 Average solution length: 8.5 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 183.4 Average search time: 0.007053196430206299 Average solution length: 47.35 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 330.125 Average search time: 0.012123554944992065 Average solution length: 68.95 /// Solved 40 puzzles from file: worst.txt Average nodes expanded: 375.375 Average search time: 0.013834601640701294 Average solution length: 78.15 /// Solved 40 puzzles from file: random.txt Average nodes expanded: 121.925 Average search time: 0.0048205554485321045 Average solution length: 34.075	Solved 40 puzzles from file: easy.txt Average nodes expanded: 12.175 Average search time: 0.0007726728916168212 Average solution length: 7.0 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 115.725 Average search time: 0.004433256387710571 Average solution length: 15.0 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 779.15 Average search time: 0.02925131320953369 Average solution length: 21.0 /// Solved 40 puzzles from file: worst.txt Average nodes expanded: 26059.075 Average search time: 0.9683151245117188 Average solution length: 30.05 /// Solved 40 puzzles from file: random.txt Average nodes expanded: 2675.875 Average search time: 0.09860233068466187 Average solution length: 16.775



What I learned:
-1.1:
--How to write a goal test for an 8-puzzle.
-1.2:
--How well IDS search performs for different difficulties of 8-puzzle:
---Exponential relationship between solution length and nodes expanded.
-1.3:
--How to calculate f-value for uniform cost search for 8-puzzle:
---Length of path to next node.
--How to calculate f-value for greedy search for 8-puzzle:
---Heuristic cost of next node.
--How to calculate f-value for A* search for 8-puzzle:
---Length of path to next node + heuristic cost of next node.
--How well each search performs for different difficulties of 8-puzzle:
---Uniform cost performs worst (exponential).
---Greedy performs best (linear) but with worse solutions.
---A* performs medium (exponential) but is best overall.
-1.4:
--How to implement tiles out of row and column heuristic for 8-puzzle.
--How to implement manhattan distance heuristic for 8-puzzle.
-1.5:
--How well each heuristic performs for different difficulties of 8-puzzle:
---TOP performs worst overall (largest rate of increase).
---TORC performs medium overall (medium rate of increase).
---MD performs best overall (lowest rate of increase).

Part 2:
python eight.py ___.txt -s ids -f ___

1. top	2. torc	3. md
Solved 40 puzzles from file: easy.txt Average nodes expanded: 32.025 Average search time: 0.0005502045154571533 Average solution length: 7.0 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 1463.925 Average search time: 0.016854679584503172 Average solution length: 15.0 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 27243.825 Average search time: 0.3032244980335236 Average solution length: 21.0 /// Solved 40 puzzles from file: worst.txt Average nodes expanded: 2714460.725 Average search time: 30.60689726471901 Average solution length: 30.05 /// Solved 40 puzzles from file: random.txt Average nodes expanded: 167634.05 Average search time: 1.8869463622570037 Average solution length: 16.775	Solved 40 puzzles from file: easy.txt Average nodes expanded: 17.05 Average search time: 0.0004268467426300049 Average solution length: 7.0 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 467.975 Average search time: 0.009436100721359253 Average solution length: 15.0 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 5869.9 Average search time: 0.12264817357063293 Average solution length: 21.0 /// Solved 40 puzzles from file: worst.txt Average nodes expanded: 439348.65 Average search time: 9.397001969814301 Average solution length: 30.05 /// Solved 40 puzzles from file: random.txt Average nodes expanded: 33957.175 Average search time: 0.7218914330005646 Average solution length: 16.775	Solved 40 puzzles from file: easy.txt Average nodes expanded: 28.925 Average search time: 0.000604015588760376 Average solution length: 7.0 /// Solved 40 puzzles from file: medium.txt Average nodes expanded: 417.9 Average search time: 0.0075040459632873535 Average solution length: 15.0 /// Solved 40 puzzles from file: hard.txt Average nodes expanded: 3091.65 Average search time: 0.052082794904708865 Average solution length: 21.0 /// Solved 40 puzzles from file: worst.txt Average nodes expanded: 223070.225 Average search time: 3.737385505437851 Average solution length: 30.05 /// Solved 40 puzzles from file: random.txt Average nodes expanded: 20439.075 Average search time: 0.3373986542224884 Average solution length: 16.775



What I learned:
-How to change IDS into IDA*:
--Set initial depth limit to A* f-value:
---Length of path to next node + heuristic cost of next node.
--Set depth-limit-reached check to compare to A* f-value:
---Length of path to next node + heuristic cost of next node.
--Set search type in current node's options to A*:
---Does not alter performance, but is a good practice.
-How well IDA* search performs for different difficulties of 8-puzzle:
--Exponential relationship between solution length and nodes expanded.
-How well IDA* search performs with each heuristic for different difficulties of 8-puzzle:
---TOP performs worst overall (largest rate of increase).
---TORC performs medium overall (medium rate of increase).
---MD performs best overall (lowest rate of increase).

```
from __future__ import print_function
from queue import PriorityQueue
import sys
import math
import time
import random
import argparse

# Code for AI Class Programming Assignment 1
# Written by Chris Archibald
# archibald@cs.byu.edu
# Last Updated January 24, 2020

# GOAL: (0 is the blank tile)
# 0 1 2
# 3 4 5
# 6 7 8

class Puzzle():
    """
    This is the 8-puzzle class.  You shouldn't have to modify it at all.
    """

    def __init__(self, arrangement):
        """
        The state (and arrangement passed in) is a list of length 9, that stores which tile is in each place
        In a solved puzzle, each place number holds the tile of the same number
        i.e. solution is state = [0,1,2,3,4,5,6,7,8]
        """
        self.state = arrangement[:]
        self.blank = None

        for i in range(len(self.state)):
            if self.state[i] == 0:
                self.blank = i

    def print_puzzle(self):
        """
        Print a visual description of the puzzle to the output
        """
        k = 0
        for i in range(3):
            for j in range(3):
                print('', end="")
                print(self.state[k], end="")
                k = k + 1
            print('')

    def get_moves(self):
        """
        The moves correspond to the motion of the tile into the blank space
        it can be U (up), D (down), R (right), or L (left)
        """
        invalid_moves = []
        if self.blank < 3:
            invalid_moves.append('D')
        if self.blank > 5:
            invalid_moves.append('U')
        if self.blank % 3 == 0:
            invalid_moves.append('R')
        if self.blank % 3 == 2:
            invalid_moves.append('L')

        base_moves = ['U', 'D', 'L', 'R']
        valid_moves = []
        for m in base_moves:
            if m not in invalid_moves:
                valid_moves.append(m)

        return valid_moves

    def do_move(self, move):
        """
        Modify the state by performing the given move.
        This assumes that the move is valid
        """
        swapi = 0
        if move == 'U':
            swapi = self.blank + 3
        if move == 'D':
            swapi = self.blank - 3
        if move == 'L':
            swapi = self.blank + 1
        if move == 'R':
            swapi = self.blank - 1

        temp = self.state[swapi]
        self.state[swapi] = self.state[self.blank]
        self.state[self.blank] = temp
        self.blank = swapi

    def undo_move(self, move):
        """
```

```
        This modifies the state by undoing the move.  For use in recursive search
        Assumes the move was a valid one
        """
        swapi = 0
        if move == 'D':
            swapi = self.blank + 3
        if move == 'U':
            swapi = self.blank - 3
        if move == 'R':
            swapi = self.blank + 1
        if move == 'L':
            swapi = self.blank - 1

        temp = self.state[swapi]
        self.state[swapi] = self.state[self.blank]
        self.state[self.blank] = temp
        self.blank = swapi

    def is_solved(self):
        """
        Returns True if the puzzle is solved, False otherwise
        """
        ######## TASK 1.1 BEGIN ##########

        if self.state == [0,1,2,3,4,5,6,7,8]:
            return True
        else:
            return False

        ######## TASK 1.1 END   ##########


    def __repr__(self):
        return "".join([str(i) for i in self.state])

    def id(self):
        """
        Returns the string representation of this puzzle's state.
        Useful for storing state in a dictionary
        """
        return self.__repr__()

class SearchNode():
    """
    Our search node class
    """
    def __init__(self,cost,puzzle,path,options):
        """
        Initialize all the relevant parts of the search node
        """
        self.cost = cost
        self.puzzle = puzzle
        self.path = path
        self.options = options
        self.h = heuristic(self,self.options)
        self.compute_f_value()

    def compute_f_value(self):
        """
        Compute the f-value for this node
        """
        ######## TASK 1.3 BEGIN ##########

        #Modify these lines to implement the search algorithms (greedy, Uniform-cost or A*)
        self.h = heuristic(self, self.options)
        self.f_value = 0

        if self.options.type == 'u':
            #uniform cost search algorithm
            self.f_value = len(self.path) # Change this to implement uniform cost search!

        elif self.options.type == 'g':
            #greedy search algorithm
            self.f_value = self.h # Change this to implement greedy!

        elif self.options.type == 'a':
            #A* search algorithm
            self.f_value = len(self.path)+self.h # Change this to implement A*!

        else:
            print('Invalid search type (-t) selected: Valid options are g, u, and a')
            sys.exit()

        ######## TASK 1.3 END   ##########

    #Comparison operator. Don't modify this or best-first search might stop working
    def __lt__(self,other):
        """
        Comparison operator so that nodes will be sorted in priority queue based on f-value
        """
        return self.f_value < other.f_value

def heuristic(node,options):
```

```
    """
    This is the function that is called from the SearchNode class to get the heuristic value for a node
    """
    if options.function == 'top':
        return tiles_out_of_place(node.puzzle)
    elif options.function == 'torc':
        return tiles_out_of_row_column(node.puzzle)
    elif options.function == 'md':
        return manhattan_distance_to_goal(node.puzzle)
    else:
        print('Invalid heuristic selected. Options are top, torc, and md')
        sys.exit()

def tiles_out_of_place(puzzle):
    """
    This heuristic counts the number of tiles out of place.
    """
    #Keep track of the number of tiles out of place
    num_out_of_place = 0

    #Cycle through all of the places in the puzzle and see if the right tile is there
    # (We ignore place 0 since that is where the blank tile goes and we shouldn't count it)
    for i in range(1,len(puzzle.state)):

        # The tile in place i ( puzzle.state[i] ) should be tile i.
        # If it isn't increment out of place counter
        # (To compare tile (string) with place (int), we must first convert from string to int as such:
        #  int(puzzle.state[i])

        if puzzle.state[i] != i:
            num_out_of_place += 1

    return num_out_of_place


def tiles_out_of_row_column(puzzle):
    """
    This heuristic counts the number of tiles that are in the wrong row,
    the number of tiles that are in the wrong column
    and returns the sum of these two numbers.
    Remember not to count the blank tile as being out of place, or the heuristic is inadmissible
    """
    ######## TASK 1.4.1 BEGIN   ##########

    # YOUR TASK 1.4.1 CODE HERE

    rows = 3
    cols = 3

    num_out_rows = 0
    num_out_cols = 0

    for i in range(rows):
        for j in range(cols):
            if (puzzle.state[i*rows+j] != i*rows)\
                    and (puzzle.state[i*rows+j] != i*rows+1)\
                    and (puzzle.state[i*rows+j] != i*rows+2)\
                    and (puzzle.state[i*rows+j] != 0):
                num_out_rows += 1
            if (puzzle.state[i*rows+j] != j)\
                    and (puzzle.state[i*rows+j] != rows+j)\
                    and (puzzle.state[i*rows+j] != 2*rows+j)\
                    and (puzzle.state[i*rows+j] != 0):
                num_out_cols += 1

    return num_out_rows + num_out_cols

    ######## TASK 1.4.1 END   ##########

def manhattan_distance_to_goal(puzzle):
    """
    This heuristic should calculate the sum of all the manhattan distances for each tile to get to
    its goal position.  Again, make sure not to include the distance from the blank to its goal.
    """

    ######## TASK 1.4.2 BEGIN   #########

    # YOUR TASK 1.4.2 CODE HERE

    rows = 3
    cols = 3

    lat_diff = 0
    lon_diff = 0

    for i in range(1,len(puzzle.state)):
        place = puzzle.state.index(i)
        lat_diff += abs((place % cols) - (i % cols))
        lon_diff += math.floor(abs((place / rows) - (i / rows)))

    return lat_diff + lon_diff

    ######## TASK 1.4.2 END   ##########
```

```
def get_tile_row(tile):
    """
    Return the row of the given tile location (Helper function for you to use)
    """
    return int(tile / 3)

def get_tile_column(tile):
    """
    Return the column of the given tile location (Helper function for you to use)
    """
    return tile % 3

def run_iterative_search(start_node):
    """
    This runs an iterative deepening search
    It caps the depth of the search at 40 (no 8-puzzles have solutions this long)
    """
    #Our initial depth limit

    depth_limit = len(start_node.path)+start_node.h #EDIT 1/3

    #Maximum depth limit
    max_depth_limit = 40

    #Keep track of the total number of nodes we expand
    total_expanded = 0

    #Keep trying until our depth limit hits 40
    while depth_limit < max_depth_limit:

        #Store visited nodes along the current search path
        visited = dict()
        visited['N'] = 0

        #Mark the initial state as visited
        visited[start_node.puzzle.id()] = True

        #Run depth-limited search starting at initial node (which points to initial state)
        path_length = run_dfs(start_node, depth_limit, visited)

        #See how many nodes we expanded on this iteration and add it to our total
        total_expanded += visited['N']

        #Check to see if a solution was found
        if path_length is not None:
            #It was! Print out information and return the search stats
            print('Expanded ', total_expanded, 'nodes')


            print('IDS Found solution at depth', depth_limit)
            return total_expanded, path_length

        # No solution was found at this depth limit, so increment our depth-limit
        depth_limit += 1

    # No solution was found at any depth-limit, so return None,None (Which signifies no solution found)
    return None, None

def run_dfs(node, depth_limit, visited):
    """
    Recursive Depth-Limited Search:

    Check node to see if it is goal, if it is, print solution and return path length
    If not and if depth-limit hasn't been reached, recurse on all children
    """
    visited['N'] = visited['N'] + 1 #Increment our node expansion counter

    # Check to see if this is a goal node
    if node.puzzle.is_solved():
        # It is! Print out solution and return solution length
        print('Iterative Deepening SOLVED THE PUZZLE! SOLUTION = ', node.path)
        return len(node.path)

    # Check to see if the depth limit has been reached (number of actions that have been taken)
    if len(node.path)+node.h >= depth_limit: #EDIT 2/3
        # It has. Return None, signifying that no path was found
        return None

    # Generate successors and recurse on them

    # Get the list of moves we can try from this node's state
    moves = node.puzzle.get_moves()

    # For each possible move
    for m in moves:
        #Execute the move/action
        node.puzzle.do_move(m)
        node.options.type = 'a' #EDIT 3/3
        node.compute_f_value()


        #Add this move to the node's path
```

```
        node.path = node.path + m
        #Add 1 to node's cost
        node.cost = node.cost + 1
        #Check to see if we have already visited this node
        if node.puzzle.id() not in visited:
            #We haven't. Now we will, so add it to visited
            visited[node.puzzle.id()] = True

            #Recurse on this new state
            path_length = run_dfs(node, depth_limit, visited)

            #Check to see if a solution was found down this path (return value of None means no)
            if path_length is not None:
                #It was! Return this solution path length to whoever called us
                return path_length

            #Remove this state from the visited list.  We only check for duplicates along current search path
            del visited[node.puzzle.id()]

        # That move didn't lead to a solution, so lets try the next one
        # First, though, we need to undo the move (to return puzzle to state before we tried that move)
        node.puzzle.undo_move(m)
        # Remove that last move we tried from the path
        node.path = node.path[0:-1]
        # Remove 1 from node's cost
        node.cost = node.cost - 1

    #Couldn't find a solution here or at any of my successors, so return None
    #This node is not on a solution path under the depth-limit
    return None

def run_best_first_search(fringe, options):
    """
    Runs an arbitrary best-first search.  To change which search is run, modify the f-value
    computation in the search nodes

    fringe is a priority queue of search nodes, ordered by f-values
    """
    #Create our data structure to track visited/expanded states
    visited = dict()

    #Variable to tell when we are done
    done = False

    #Main search loop.  Keep going as long as we are not done and the FRINGE isn't empty
    while not done and not fringe.empty():

        #Get the next SearchNode from the FRINGE
        cur_node = fringe.get()

        #Add it to our set of visited/expanded states (join creates a string from the state)
        visited[cur_node.puzzle.id()] = True

        #Don't continue if the cost is too much
        if cur_node.cost > 200:
            #None of the puzzles are this long, so we shouldn't continue further on this path
            continue

        #Check to see if this node's puzzle state is a goal state
        if cur_node.puzzle.is_solved():
            #It is! We are done, print out details
            done = True
            print('Best-First SOLVED THE PUZZLE: SOLUTION = ', cur_node.path)
            print('Expanded ', len(visited), 'states')
            return len(visited), len(cur_node.path)

        else:
            #Generate this SearchNode's successors and add them to the FRINGE

            #Get the possible moves (actions) for this state
            moves = cur_node.puzzle.get_moves()

            #For each move, do the move, create SearchNode from successor, then add to FRINGE
            for m in moves:
                #Create new puzzle that new node will point to
                np = Puzzle(cur_node.puzzle.state)

                #Execute the move/action
                np.do_move(m)

                #Add to the FRINGE, as long as we haven't visited that puzzle
                if np.id() not in visited:
                    #Create the new SearchNode
                    new_node = SearchNode(cur_node.cost + 1, np, cur_node.path + m, options)

                    #Add it to the FRINGE, along with its f-value (stored inside the node)
                    fringe.put(new_node)

    #We didn't find a solution
    if not done:
        print('NO SOLUTION FOUND!')
        return None,None
```

```
def getOptions(args=sys.argv[1:]):
    parser = argparse.ArgumentParser(description="8-Puzzle Solver.")
    parser.add_argument('file', metavar='FILENAME', type=str, help="File of puzzles to solve")
    parser.add_argument("-s", '--search', help="Search type: Options: ids (iterative deepening search) or bfs (best first search)", default='ids')
    parser.add_argument("-f", '--function', help="Heuristic function used: Options: top (tiles out of place), torc (tiles out of row/column), or md (manhattan distance)",default='top')
    parser.add_argument("-t", '--type', help="Evaluation function type: Options: g (greedy), u (uniform cost), or a (a-star)", default='u')
    options = parser.parse_args(args)
    return options

if __name__ == '__main__':

    #Get command line options
    options = getOptions()
    print(options)
    print('Searching for solutions to puzzles from file: ', sys.argv[1])

    #Open puzzle file
    pf = open(options.file,'r')

    #You can modify the maximum number of puzzles to solve if you want to test on more puzzles
    max_to_solve = 40

    #Variables to keep track of solving statistics
    num_solved = 0
    exp_num = 0
    tot_time = 0.0
    path_length = 0

    for ps in pf.readlines():
        print('Searching to find solution to following puzzle:', ps)

        #Create puzzle from file line
        a = [int(i) for i in ps.rstrip()]
        p = Puzzle(a)

        #Print the puzzle to the screen
        p.print_puzzle()

        #Create the initial search node corresponding to the given puzzle state
        start_node = SearchNode(0,p,'',options)

        #Create the priority Queue to store the SearchNodes in
        pq = PriorityQueue()

        #Insert the initial state into the Queue
        pq.put(start_node)

        #Get initial timing info
        start = time.time()

        #Run the given search search (each returns number of nodes expanded and the length of the path found)
        if options.search == 'bfs':
            #Run the best-first searches
            exp, pl = run_best_first_search(pq, options)
        elif options.search == 'ids':
            #Use this line to run the iterative deepening-search
            exp, pl = run_iterative_search(start_node)
        else:
            print("Search option not valid. Can be bfs or ids")
            sys.exit()

        if exp is None:
            print('PUZZLE NOT SOLVED')
            break

        #Keep track of statistics so we can compare search methods
        exp_num += exp
        path_length += pl
        print('Solution path length is : ', pl)

        #Calculate Timing info
        end = time.time()
        tot_time += end - start
        num_solved += 1

        #Stop after we have solved the specified number of puzzles
        if num_solved >= max_to_solve:
            break

    print('Done with solving puzzles.\n\n')

    #Print out statistics about this batch
    if num_solved > 0:
        print('Solved', num_solved, 'puzzles from file: ', sys.argv[1])
        print('Average nodes expanded: ', float(exp_num) / float(num_solved))
        print('Average search time: ', tot_time / num_solved)
        print('Average solution length: ', path_length / num_solved)
    else:
        print('A puzzle was not solved.  This means you haven\'t correctly implemented something. Please double check your code and try again.')
```